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RELIABILITY CENTERED MAINTENANCE STUDY - FINAL REPORT

DAAG 39-77-C-0169

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Final Report for Period July 1977 - August 1978

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The implementation of the Army's Reliability Centered Maintenance (RCM) is assessed. A three phase study is reviewed here. Intensive examination of various approaches to RCM implementation included analysis of several programs from the Army, Navy, and Air Force, and examination of potential application of principles and methods employed by these programs to Army RCM.

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GLOSSARY

ACE - Analytical Condition Evaluation
AFLMC - Air Force Logistic Management Center
AMCP - Army Materiel Command Pamphlet
AMP - Analytical Maintenance Program
AMS - American Management Systems Incorporated
AOAP - Army Oil Analysis Program
ASOAP - Army Spectrometric Oil Analysis Program
AVIM - Aviation Intermediate Maintenance
AVUM - Aviation Unit Maintenance

BAP - Benefit Assessment Program
BITE - Built-In-Test-Equipment

CEM/SE - Communications, Electronics, Meteorological/Aircraft Support Equipment

DMWR - Depot Maintenance Work Requirement

EM - Equipment Monitoring
ESC - Equipment Serviceability Criteria

FDLA - Fault Detection and Location Analysis
FMAE - Failure Mode Effects Analysis
FMECA - Failure Mode Effects and Criticality Analysis

ILS - Integrated Logistics Support
IPR - In-process Review
IRAR - Inspect and Repair as Required
IRON - Inspect and Repair Only as Necessary

LCC - Lockheed California Company
LEAP - Logistical Efficiencies to Increase Army Power
LSA - Logistics Support Analysis
LSAR - Logistics Support Analysis Record

MAVIS - Model for Analysis of Vehicle Inspection System
MCF - Master Configuration File
MOM - Maintenance Operation Management
MPIP - Maintenance Posture Improvement Plan
MPM - Maintenance Program Management
MPOM - Maintenance Program Operation Management
MRB - Maintenance Review Board

MSDP	- Maintenance System Development Program
MSG	- Maintenance Study Group
MSI	- Maintenance Significant Items
OCM	- On-Condition Maintenance
OMB	- Office of Management and Budget
OSD	- Office of the Secretary of Defense
PI	- Profile Index
PMCS	- Preventive Maintenance Checks and Services
PRAM	- Producibility, Reliability, Availability, Maintainability
R/M	- Reliability/Maintainability
RCMIT	- RCM Implementation Team
RISE	- Reliability Improvement of Selected Equipment
RS	- Repetitive Service
SAG	- Study Advisory Group
SAMS	- Standard Army Maintenance System
SMFOP	- Scheduled Maintenance Frequency Optimization Program
SS	- Sequential Service

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1.0 SUMMARY

1.1 Scope and Approach

This is the final report of an independent assessment of the Army's implementation Reliability Centered Maintenance (RCM) conducted under contract DAAG-39-77-C-0169 awarded to the Martin Marietta Corporation on 23 August 1977. Martin Marietta conducted the assessment in three phases, the first being initial contact with responsible implementation commands, DARCOM, MRSA and other involved organizations for in-depth familiarization with all RCM and RCM-related efforts. The second phase consisted primarily of on-site review of activities at commercial airline facilities, Navy and Air Force logistics and maintenance installations, and maintenance directorates at the Army Research and Development Command and at the five Army Materiel Readiness Commands. Intensive examination and review of interrelated approaches to RCM implementation characterized the third phase, in which the aims, objectives, procedures, problems, and successes of the programs were reviewed, compared and evaluated for degree and depth of current and past benefits and future potential for implementation of RCM.

To establish direction for the assessment the RCM Study Advisory Group (SAG) and Martin Marietta jointly selected five candidate systems, one from each readiness command, for assessment of RCM activities. The five candidate systems and the respective commands are the UH-1H Helicopter (TSARCOM), TOW Weapon System (MIRCOM), M-113 Armored Personnel Carrier (TARCOM), AN/VRC-12 Radio Set (CERCOM) and M-110 SP Howitzer (ARRCOM). Also selected for evaluation of RCM on a developmental system was the AN/TPQ-37 Radar Set, which is the responsibility of ERADCOM. Inherent to the contract requirements was an evaluation of the retention value of Army programs initiated prior to RCM which contained elements common with RCM.

Analyses of Navy and Air Forces RCM programs were required to determine how these services were complying with the DoD directive for implementation of RCM. Also, a review of the airline industry was conducted to determine how MSG-2 has impacted its maintenance planning.

1.2 Background

RCM is based on Airline Manufacturer's Maintenance Program and Planning Document, MSG-2 which describes a specific airline maintenance concept for developing maintenance programs for airframes and engines. This concept was so successful in its initial application that some airlines have applied it

to maintenance programs for older aircraft. MSG-2 utilizes engineering analyses and decision logic processes to develop more effective maintenance programs. MSG-2's prime purpose is to maintain operating reliability and safety levels originally designed into the equipment, at minimum practical cost. This recognizes that maintenance programs cannot correct deficiencies in inherent design reliability levels of flight equipment, that maintenance programs can only prevent deterioration of these inherent levels. MSG-2 logic is that maintenance services should be applied to the entire aircraft, then sequentially to its subassemblies. Finally, MSG-2 emphasizes the integration of maintenance services at all levels.

The MSG-2 concept was endorsed by the Office of Secretary of Defense (OSD) to be specifically applied to military aircraft programs. In 1976 the descriptive term Reliability Centered Maintenance (RCM) was suggested by OSD to encompass the application of the new comprehensive maintenance ideas to new aircraft fielded in 1977 and requiring other military commodities to be included by end of FY 79.

The Department of the Army contended that many aspects of RCM were already being implemented in existing Army maintenance programs through various maintenance improvement programs and policies initiated before RCM was formulated. It was also recognized that further benefits could still be derived from formal application of RCM by maintenance planners and design engineers, who developed maintenance programs for both fielded systems equipment and developmental items. The Department of the Army has established a goal to expand the concept and formally apply the principles of RCM in the design and maintenance of major Army systems and equipment.

A contract was awarded Martin Marietta to provide Department of the Army with an independent assessment of RCM implementation on past and present programs to determine where benefits can be derived. Under this contract Army programs that contained or should have contained elements of RCM were identified, analyzed, and evaluated with respect to the principles of RCM and MSG-2. Examples of these are the Army Oil Analysis Program (AOAP), Project Inspect, Project LEAP, PMCS Review, DMWR Scrub, etc.

1.3 RCM-Related Activities

Several RCM-related programs have been initiated in recent years which have goals in common with RCM, e.g., reducing cost of maintenance while retaining inherent reliability, or which revise a maintenance activity through similar processing methods. Some of these were implemented prior to RCM, for example, the Army Oil Analysis Program (AOAP), On-Condition Maintenance (OCM) for aircraft, Project LEAP-Issue 127, Three-level Maintenance for aircraft, and Project Inspect. Others, such as Preventive Maintenance and Checks Services (PMCS) Review, Depot Maintenance Work Requirement (DMWR) Scrub, and extending OCM to tracked vehicles, were initiated after RCM was endorsed by OSD. These programs, along with other major interrelated Army programs are discussed in detail in Section 3 of the final report.

1.4 Investigation of RCM Implementation

1.4.1 UH-1H UTILITY HELICOPTER - TSARCOM

The initial review of the UH-1H activities at TSARCOM revealed that RCM-type efforts were implemented on aircraft considerably before RCM became a program entity. This was due to the emphasis placed on safety and reliability aspects of aircraft operations, which resulted in high-cost scheduled maintenance programs.

Since 1957 numerous equipment failures have been averted through use of the AOAP. Although there is no pre-AOAP data available to determine the actual benefits derived, data collected during the program shows that it is of sufficient value to be accepted for all types of vehicles Army-wide.

The OCM program was initiated in 1973 to change the method of overhaul candidate selection from a hard time limit basis to an aircraft condition basis, as revealed in annual inspection by an evaluation team. Since that time overhauls of airframes have been reduced from 700 to 350 annually. Part of the 50 percent reductions, which resulted in $45 million yearly savings, is attributed to reduced flying hours. Quantification of savings relationships between OCM and the usage reduction has not been attempted.

ADM-DMWRs for aircraft were developed specifically to support the OCM program. They are based on the premise that an airframe assembly or component is removed only after a detailed analysis shows it to be unserviceable or if removal is required for access expediency. No data is available to determine cost savings resulting from ADM-DMWR application. The DMWR scrub effort on jet engines is being pursued through award of a contract to study depot engine overhaul and repair data. This study data, due at end of FY 78, is intended for use in revising power plant overhauls under ADM-DMWR philosophy.

Implementation of Three-Level Maintenance, reassigning over 50 percent of DSU functions to the organizational level and the balance to GSU, was approved in 1974 and initiated in 1976. Savings data has not been available to date but it is believed that aircraft downtime has been decreased. Previous data from the 1969 test of this concept in Southeast Asia showed an increase in operational readiness from 64 percent to 85 percent, with concurrent flying hour usage up from 63 percent to 88 percent (First Cavalry experience).

Project Inspect was a formal test program that evaluated the use of a reduced maintenance concept on Army helicopters. Thirty eight thousand flying hours were flown by 120 helicopters, with 60 maintained under the old preventive maintenance system and 60 under the new concept. Analysis of failure, usage, and maintenance experience data showed a 73 percent reduction in maintenance manhours per flying hours, and a 13 percent decrease in maintenance cost per flying hour while operational readiness was increased by 3 percent. The success of this test fostered implementation of Phased Maintenance on Army aircraft worldwide in 1977.

Phase Maintenance inspection intervals, developed from MAVIS model computations of the test data, are spread over an 800 hour cycle rather than a complete unit inspection every 100 hours. TSARCOM analysis of the new versus the old maintenance manual tasks shows a 6 percent reduction of total tasks required for complete inspection (dollar savings not made available). Additional reductions are anticipated when daily and special inspections are considered for Phased Maintenance programming.

It is TSARCOM's position that the objectives of RCM have been accomplished through the above programs. They have achieved reduced maintenance cost by optimizing inspection intervals that also retain inherent equipment reliability and safety. TSARCOM believes that the MSG-2 logic, which was developed for high altitude aircraft containing many redundant components, is not applicable to UH-1H helicopters. The UH-1H flies nap-of-the-earth operations, incorporates minimum redundancy and uses a small crew. TSARCOM feels that the current programs produce better aircraft maintenance than is attainable through RCM processing alone, and that development of RCM engineering analysis and decision logic in addition to the current effort would not be cost effective.

The Martin Marietta survey of UH-1H and other aircraft maintenance activities has resulted in the following assessment:

1 Maintenance program modifications initiated prior to RCM formalization by the Army have been beneficial.

2 Project Inspect data appears to be accurate and useful for maintenance program planning to date.

3 Future maintenance programming efforts will require updated maintenance experience data.

4 MAVIS is a valid tool for determining aircraft inspection intervals where sufficient data is available.

5 Development of a UH-1H-oriented decision logic by TSARCOM engineers for use with MAVIS could yield cost-effective benefits.

6 The ADM-DMWR program for airframes is reasonably comparable with DMWR scrub. The jet engine overhaul and repair study should produce appropriate data for power plant DMWR scrubbing.

Exhibit I of this report documents the details of the UH-1H/TSARCOM survey.

1.4.2 TOW Antitank Assault Weapon System - MIRCOM

The survey of MIRCOM was conducted to evaluate the RCM implementation efforts on the TOW Heavy Anti-Tank/Assault Weapon System. Although MIRCOM

did not establish a formal RCM program, it did engage in independent RCM related activities, including:

1 Revision of PMCS including integration of ESC

2 A review of DMWRs and depot work policies

3 Application of sound maintenance engineering practices to solve field reported problems.

Revision of the PMCS was completed in October 1976, which preceded the formalization of the Army RCM program.

The PMCS Review was accomplished by technical writers, who revised TM-9-1425-470-12, Operator's and Organizational Maintenance Manual for the TOW Weapon System, with approval of maintenance engineering personnel, who based their decisions on engineering judgement. The revision showed an increase of tasks from 8 to 103, but these now included integration of ESC tasks and a reduced scope of each task so that the overall maintenance work is virtually unchanged. Manhour requirements for the eight old tasks and for the 103 new tasks has not been available for comparison. Other PMCS tables undergoing review at MIRCOM consist of Chaparral, DRAGON, FAAR and LCSS with only LCSS showing significant reduction. RCM logic and engineering analysis were not used for any of these PMCS revisions partially due to lack of adequate guidance at the time of review.

Differences in opinion between MIRCOM and DARCOM regarding the validity of revising or scrubbing the DMWR for TOW are apparent. Exhibit II documents, in chronological order, the significant related events pertaining to these contrasting opinions on whether the Inspect and Repair Only as Necessary (IROAN) philosophy for overhauling TOW equipment constitutes conformance to DMWR scrub requirements. A review of TOW reconditioning operations was held at Anniston Army Dept on 9 November 1977, which resulted in MIRCOM reinforcing their belief. No objection was voiced by DARCOM or DESCOM representatives. Depot personnel, at the request of the MIRCOM Maintenance Directorate have reviewed TOW DMWRs and have suggested changes to relax requirements and criteria for scratches, dents, cuts, discolorations, and painting preparation. There appear to be few additional benefits to be derived from prolonging the TOW-DMWR scrub program.

The survey brought out the fact that a strong maintenance engineering effort to resolve problems developing in the field is conducted by MIRCOM (resolver noise, battery charging indications, and higher NI-CAD battery replacement problems are examples). These are logical items for application of failure experience data to decision logic, which could result in significant benefits.

1.4.3 M-113 Armored Personnel Carrier - TARCOM

Accomplishment of the survey of TARCOM RCM implementation on the M-113 Armored Personnel Carrier indicated that review of M-113 alone would not

present a representative view of TARCOM's RCM achievements. Therefore, the investigation was extended to cover all RCM efforts to make the survey cost effective.

No single tank or automotive product had experienced a comprehensive RCM effort but six RCM-related programs had been implmented in varying degrees. These are DMWR Scrub, Equipment Survivability Criteria, On Condition Depot Maintenance Selection, AOAP, Review of PMCS and RISE. Details on each of these programs are contained in Exhibit III with discussion in this summary devoted to results.

DMWR Scrub on M-113 was contracted to Food Machinery Corporation, where an RCM-type decision logic diagram was developed for the purpose and applied to the equipment. The decision logic used was narrow in scope and could not be used effectively to identify all the possible benefits. Absence of regulations, explicit instructions and guidelines from higher headquarters has contributed to confusion on procedures and goals on this program.

On Condition Maintenance selection of combat vehicles for overhal was studied by TARCOM, in conjunction with ARRCOM, and supported by the Material Systems Analysis Activity, Aberdeen Proving Ground, Maryland, to define a new vehicle overhaul policy. TARCOM SOP 705-5 addresses itself to operation of a special project office, within the Program Management Branch, for administration of a pilot inspection program on a specified group of M60A1 tanks. As a part of this program, through March 1978, the following vehicle inspections have resulted: 13 of 60 vehicles with an excess of 6000 miles, 15 of 44 vehicles with an excess of 5000 miles, and 14 of 28 vehicles with less than 5000 miles being selected for overhaul. Of the 132 vehicles inspected, 42 (31.9 percent) were selected as overhaul candidates. Subsequently, the total number of vehicles inspected has increased to 171, of which 48 (28.1 percent) have been selected as overhaul candidates.

PMCS reduction was accomplished prior to RCM by response to Project LEAP (no decision logic used) and again when PMCS review was initiated. TARCOM under PMCS review developed its own logic but was hampered by incomplete and confusing instructions which required several manual revisions. Basically, the changes show that the PMCS task can be reduced effectively. For example the Goer PMCS tasks were reduced from 152 to 83 with significant reduction in time.

1.4.4 AN/VRC-12 CERCOM

The survey of the RCM activities on the AN/VRC-12 radio set showed that CERCOM has a positive attitude toward acceptance of the Army RCM program. It has displayed and understanding of the underlying principles of RCM, has briefed its key personnel on program details, and in general has promoted RCM at all levels of the command.

Implementation of RCM on the AN/VRC-12 radio set at this time does not include a formal or comprehensive RCM program. Effort has been made to revise the PMCS and to integrate ESC on the VRC-12 and other systems that are under cognizance of this command; and preliminary planning to scrub the VRC-12 DMWR has been accomplished.

PMCS revision effort which included integration of Equipment Serviceability Criteria (ESC) was conducted on the AN/VRC-12 and other electronic equipment systems by CERCOM in 1977. Subsequently, DARCOM's Command Logistics Review Team concluded that the revised PMCS were inconsistent with RCM principles. CERCOM intends to redo these PMCS tables using the DARCOM logic included in their draft RCM guide data April, 1978. As a result of the original revision, the AN/VRC-12 PMCS includes a number of items directly related to field problems (Red Team survey recommendations) providing a good base on which to apply RCM guidelines and logic.

This command is involved in management of a product line that, in comparison with other equipment, possesses limited potential for RCM application. Electronic components demonstrate a constant failure rate over most of their expected life and the time from onset of determination to actual failure is very short or economically not discernible. Therefore, CERCOM is in need of assistance to identify possible areas or methods for RCM implmentation. Ring time measurements, used on shipboard radar, and marginal checking, as applied to digital computers, are examples of techniques that can be used to detect deterioration or failed components and therefore could yield reduced system failures if added to maintenance programs by RCM processing.

1.4.5 M-110 Self-Propelled Howitzer - ARRCOM

ARRCOM management and RCM action personnel have taken positive attitudes and actions toward achieving RCM benefits. An RCM Implementation Team (RCMIT) was established by SOP 750-11 providing authority, facilities, procedural steps and funding for the team. Monthly team meetings are held to track RCM progress on each weapon system under ARRCOM cognizance. The DMWR has been treated as a separate activity and not placed under control of RCMIT.

Under the ARRCOM procedure, ten steps are required for RCM revision of PMCS, of which only the first step has been completed for the M-110 SP Howitzer. Step no. 6 has been completed for the M-60 tank, and since RCM procedures and maintenance actions on both systems are similar, this survey investigated the M-60 processing problems and accomplishments along with the M-110 status in order to provide an accurate assessment of RCM implementation by ARRCOM.

The ARRCOM comparative analysis for the M-60 Operator's Manual revision shows a 47 percent reduction in tasks and 13 percent decrease in manpower required. ARRCOM's analysis for the M-60 Organization Maintenance Manual revision shows a 53 percent task reduction but calculation of required manpower at that point in the process was not feasible.

M-110 hull and turret DMWRs have been revised under the DMWR scrub program using inputs from Letterkenny Army Depot. ARRCOM requested that the depot base its inputs on the Inspect and Repair as Required (IRAR) concept since IRAR-type repairs are 50 percent less when compared with DMWR overhaul. Thirty M-110 howitzers were scheduled for overhaul in fiscal year 78, ten of which were earmarked for validation of the revised DMWR drafts.

Additional ARRCOM efforts relating to RCM are the AOAP, which is scheduled for implementation on M-110 turrets in September, 1978 (the hull, including the engine, etc., is currently evaluated by AOAP under TARCOM/MRSA administration,) and the OCM program for overhaul candidate selection, which is under ARRCOM study for possible application to M-110 turrets.

The assessment of M-110/ARRCOM efforts toward RCM implementation indicates the following:

1 Engineering analysis of experience data has not been used as input for decision logic processing. This has resulted in at least two omissions of potentially cost-effective tasks in the revised drafts for M-60 PMCS manuals. These two cases are included in the detailed evaluation contained in Exhibit V.

2 Personnel working PMCS reduction of both M-60 and M-110 RCM misinterpreted the meaning of the word "failure" in DARCOM's draft logic diagram issued in January, 1978. The interpretation used could result in a different logic pathway for a "yes" answer to question No. 1 than if the intended interpretation (MSI failure) was used.

3 As far as this survey could determine, RCM decision logic was not employed in revising the two M-110 DMWR drafts.

4 The primary reason for the RCM implementation problems encountered by ARRCOM appears to be insufficient guidance at the working level. A secondary factor (contributing to PMCS revisions only) is that Equipment Specialist rather than engineers were assigned to perform RCM analysis of PMCS for the weapon systems.

1.4.6 AN/TPQ-37 (Artillery Firefinder) Radar Set - ERADCOM

The AN/TPQ-37 (Artillery Firefinder) Radar Set, under cognizance of ERADCOM, was designated by the SAG as the developmental system assessment candidate for Army implementation of RCM. The ERADCOM survey revealed that the AN/TPQ-37 was out of the development stage and in the low rate initial production phase.

The RCM activity at ERADCOM has been limited to supplying the system contractor with RCM-related documents and guidelines, including the MSG-2 document and the CERCOM RCM Implementation Guide. The ERADCOM personnel were advised that the MSG-2 document was designed for use on aircraft

and that the CERCOM RCM guide was developed for application to fielded systems. Application of Appendix C to AMCP 750-16, DARCOM Guide to Logistics Support Analysis (LSA), is the intended method of RCM implementation on new systems.

ERADCOM has attempted to influence the system contractor's RCM efforts toward identification of wearout or hard time replacement items. At the time of the survey no contractor RCM accomplishments had been reported to the Firefinder Project Office. ERADCOM plans to pursue contractor RCM accomplishment reporting at subsequent Firefinder program Integrated Logistics Support (ILS) review meetings.

Although the ERADCOM survey did not identify any viable RCM activity it did focus on potential problem areas in implementing RCM on developmental systems. For example, the Firefinder contractor is tasked with conducting LSA as part of the development effort, but the requirement to perform a Failure Mode Effects and Criticality Analysis (FMECA) does not exist. Exclusion or curtailment of a FMECA is common in system development efforts and can be detrimental to the effective use of Appendix C to AMCP 750-16 as the RCM implementation vehicle. When LSA is not a specified development requirement or a FMECA is not included as a supporting requirement, no alternate methods for RCM implementation on new systems exist.

1.4.7 Army Reserve Unit AMSA-49A, McCoy Airport, Orlando

This unit was visited in January, 1978 to obtain an overview of maintenance activities and determine extent of application of RCM principles on UH-1H and OH-58 helicopters and RV-80 fixed wing aircraft. RCM as a program entity has not been implemented, but the RCM-related activities already included in this maintenance program include Phase Maintenance, AOAP, On-Condition Maintenance, and other special techniques as health indicator tests for jet engines, NI-CAD battery temperature indicators, and Vibrex machine tuning of helicopter rotor hubs. The overall capability of civilian maintenance personnel exceeds that of their regular Army counterparts, due to more years of mechanical experience and no requirements for military training or non-maintenance activities. Capability of the AMSA-49A personnel for understanding and manipulating RCM decision logic was apparently high, indicating that the use of such personnel in readiness command RCM program development could be beneficial.

1.4.8 Commercial Airlines

Maintenance programs for new commercial aircraft are developed in accordance with FAA regulations and are collectively developed by the manufacturer, airline customers, and FAA. MSG-2 philosophy is used in maintenance program development. Airlines must perform maintenance according to this program for the first year of operation after which changes can then be made with FAA approval. Some airlines use MSG-2 for determining changes although others say it does not fit their needs or it is too costly for their operation. To institute an MSG-2 maintenance program, minimum requirements are establishment of a failure mode analysis program in con-

junction with data collection and analysis. Those airlines which have used MSG-2 programming for years have been unable to identify the actual savings attributable to MSG-2 strategy accurately, due to constantly changing maintenance conditions. Eastern, United, Frontier and Flying Tiger were the four air carriers surveyed.

1.4.9 Navy Activities

To facilitate the review and analysis of Navy programs using MSG-2 and RCM principles, three Naval facilities were surveyed: NARF, Jacksonville, Florida; NAILSC, Patuxent River, Maryland; and NAVSEASYSCOM, Arlington, Virginia. The Navy RCM program for aircraft is identified as the Analytical Maintenance Program (AMP) and for ships and non-aeronautical equipment as Maintenance System Development Program (MSDP).

Both AMP and MSDP have made extensive use of the MSG-2 approach and have placed strong emphasis on FMEA, assignment of RCM personnel who possess detailed knowledge of systems undergoing RCM program development, and sustaining engineering.

One of the early successes of the AMP was its application to the P-3 aircraft. A 21 percent reduction in maintenance at the organizational and intermediate levels and 15 percent at depot level were realized. The P-3 aircraft now goes to depot at five year intervals instead of the previous three year cycle. A pilot program for MSDP will be tested on the FF1052 class ship USS Roark.

NAVSEASYSCOM has identified major obstacles in attempting to implement RCM.

1 The Navy did not purchase technical documentation to MIL-STD specifications for many of the major components of the ship.

2 They feel they share a common problem with the Air Force and the Army, in that DOD guidance has not been adequate to accomplish the RCM task.

3 The Navy does not have a cost benefit methodology that will provide before an after comparisons.

1.4.10 Air Force Activities

The Air Force approach to RCM draws heavily on MSG-2 methodology, using engineering analysis and the logic decision process to analyze and justify each maintenance task. The decision logic has been modified from MSG-2 in that military considerations are taken into account. In most cases, the Air Force has contracted with equipment manufacturers to perform engineering analysis and decision logic application for aircraft. Considerable reduction of maintenance tasks characterizes the Air Force RCM efforts as can be seen in the results achieved in the B-52 program,

i.e., 35 hardtime tasks were reduced to 17, while the 225 on-condition tasks and 1,947 condition monitoring tasks were reduced to 241 and 948.

Studies have been conducted and plans have been established to expand the Maintenance Posture Improvement Program (MPIP), the Air Force version of RCM, to include Communication/Electronic, Meteorological equipment as well as aircraft support equipment. However, initial studies indicate the return on investment for support equipment may be minimal.

The C-141 aircraft is being used as a test case to evaluate benefits per an RCM, C-141 Benefit Assessment Program Plan. This plan does not address impact on maintenance manpower, TO&E, or material costs. It contains no instructions for converting any impact to dollar savings or comparison of pre-RCM with post RCM costs.

A considerable number of guidance documents were issued by the Air Force to initiate their MPIP activities, and funds were allocated to permit contracting of most of the efforts to the prime aircraft and engine contractors. The Air Force survey was conducted at three of their facilities: Headquarters of Air Force Logistic Command, Sacramento Air Force Logistics Center and Warner Robins Air Force Logistics Center.

1.4.11 MAVIS Model

The model for Analysis of Vehicle Inspection Systems (MAVIS) was originally developed by Radio Corporation of America (RCA) for processing of Project Inspect field test data on UH-1H and CH-47 helicopters. It primary purpose is to accept the field experience data, including some RCM-type inputs such as item failure percentages, safety citicality and repair manhours for failure corrections, and provide information used to optimize inspection intervals. MAVIS has been utilized by TSARCOM to assist in revising the periodic maintenance system for all aircraft into a Phased Maintenance program wherein an 800 hour cycle is required to fully inspect the aircraft.

This system of maintenance planning is believed by TSARCOM to provide a better maintenance program than is attainable using RCM processing alone. The MAVIS model, however, is not a decision-making tool and cannot replace human judgment regarding consequences of assembly or component failure, and it does not have output comparable to an RCM condition monitoring decision for maintenance tasking.

Very extensive and comprehensive reliability and maintainability data are required to properly utilize this model for developing maintenance programs. This volume of data has not been found available for non-aeronautical equipment in the Army.

1.4.12 Appendix C to AMCP 750-16

Appendix C to AMCP 750-16 (DARCOM Guide to Logistics Support Analysis), "Analysis Guidelines for Determination of the Maintenance Plan Using the

Principles of Reliability Centered Maintenance," provides the required guidelines to include RCM in the LSA for formulation of system/equipment maintenance plans. The guidelines include instructions for the application of RCM on systems/equipment and their components to identify maintenance planning data. Inherent to the LSA is an FMECA which, coupled with the decision logic provided in Appendix C, makes the overall LSA process highly compatible with the principles of RCM. Appendix C modifies the LSA "B" sheet by adding an RCM analysis section, which facilitates recording of logic decisions and provides traceability for the RCM analysis.

Generally, Appendix C meets the requirements to implement RCM in new equipment maintenance planning, including description of decision logic and procedures for determining and recording RCM tasks and their intervals. Modifications to the decision logic and other portions of Appendix C are recommended in detail in Exhibit XI to render it fully responsive to the principles embodied in RCM strategy and concept.

1.5 Conclusions

The following conclusions have been drawn as a result of this independent evaluation of Army RCM implementation:

1 RCM has not been fully and accurately defined

2 The Army has not implemented a comprehensive RCM program on any system or product

3 Insufficient RCM guidance has been provided to Readiness and R&D Commands, and program planning has not been systematically developed

4 Readiness commands do not have capability for developing FMEA

5 Accurate and dependable field or test data are generally not available

6 RCM logic diagrams developed have been limited in scope and include complex rather than simple questions

7 Instructional courses for RCM training have not reached the working level

8 Navy and Air Force RCM programs contain elements which are potentially useful to the Army

9 Some maintenance improvement programs have produced results that can be compared with RCM potential results objectives

10 Development of new techniques for fault detection and location is needed, particularly for electronic equipment

11 Audit trails of RCM decision and processing are not generally established

12 RCM sustaining engineering has not received adequate development

13 RCM terminology is confusing and usage has resulted in misunderstandings

14 Monies to perform LSA and FMEA on development programs are not earmarked for that purpose

15 RCM has not been implemented on a developmental system

16 Analysis of exact cost benefits achieved from revised maintenance has not been feasible to date.

1.6 Recommendations

It is recommended that greater in-depth study of RCM documentation be accomplished by the Army, including review of Navy program elements and the return on investment estimated by the Air Force from aircraft support equipment RCM studies. Additional recommendations are that the Army:

1 Develop and publish a formal RCM definition

2 Develop complete and thorough RCM guidance and instructional courses, and disseminate these to the RCM working level

3 Provide the resources needed by Readiness Commands to obtain FMECA's (manpower and dollars)

4 Support acquisition of field operating and maintenance data

5 Develop methodology for preparation of an RCM FMEA and require its usage on systems which will provide a good return on investment

6 Require RCM decision logic diagrams for each type of system

7 Develop a comprehensive RCM program for at least one major system in each command

8 Retain all the successful RCM-related programs already in effect

9 Develop new techniques in fault detection and location, particularly in electronic equipment

10 Require documentation of RCM audit trails

11 Require establishment of RCM sustaining engineering functions in each Readiness Command

12 Establish a policy for systematically developing future RCM programs or modification

13 Revise RCM terminology as suggested in Section 3

14 Select a valid developmental system for assessment of RCM implementation

15 Dedicate monies for performance or LSA and FEMA to that end and do not allow them to be used for other activities

16 Require RCM sustaining engineering to be implemented during the development phase of new systems.

2.0 INTRODUCTION

This report contains the results of the activities conducted in support of the Department of the Army (DA) contract, DAAG-39-77-C-0169, 23 August 1977, U.S. Army Reliability Centered Maintenance (RCM) Implementation Assessment, which was issued to the Martin Marietta Corporation, Orlando Division, Orlando, Florida. The 12-month contract was let to assess the relationship of past Army programs to RCM principles and determine whether present programs are effectively implementing RCM.

2.1 Background

The experience of commercial airline operators and aircraft manufacturers was that formulation of scheduled maintenance programs for new aircraft can be developed more efficiently and economically through decision logic processes. A group of representatives from the airlines community developed handbook MSG-1, "Maintenance Evaluation and Program Development," dated July 1968, which included decision logic and procedures for the development of the maintenance program for the Boeing 747.

As additional wide bodied aircraft came into being the MSG-1 procedures were updated to make them applicable to the new aircraft types. Updating of existing decision logic and deletion of 747 peculiar data resulted in a universal document, designated MSG-2. The approach for the development of the maintenance requirements outlined in MSG-2 was approved by the Federal Aviation Agency (FAA) and adopted by the Air Transport Association (ATA). Application of these MSG-2 principles has resulted in significant savings in operation and support costs, for the airlines surveyed while required reliability and safety levels have been maintained effectively.

The Department of Defense (DoD) acknowledged that potential benefits could be derived through its application on all military equipment. Citing the savings realized by the airlines in their application of MSG-2, DoD ordered the MSG-2 concept to be applied to all aircraft fielded in fiscal year (FY) 1977, and to all in-service aircraft and other military equipment by the end of FY 1979. The Army RCM concept evolved as a direct result of this order.

A contract was then let to the Martin Marietta Corporation's Orlando Division to conduct an independent evaluation of the Army's past efforts and future plans for implementation of RCM for all levels of Army maintenance. Its initial approach was as follows.

The Army's hardware requirements had to be understood from the outset to be radically different from that of the commerical airlines. First, the environment in which the Army operates is more severe and demands more from the equipment. Second, while the airline mission is safety oriented, with the purpose of providing maximum passenger comfort while producing maximum profit, the Army must maintain its combat effectiveness in sustained combat situations. For these and other reasons the maintenance requirements of the airlines and Army differ markedly in their requirements. Therefore, a valid comparison of military and commercial missions and hardware support requirements is difficult to develop.

Examination of the MSG-2 decision logic applied during the analytical process of aircraft design indicates that it is well suited for use in development of a maintenance program for commerical aircraft. This does not mean that it can be applied universally and arbitarily to the Army. On the contary, it was necessary to modify the logic extensively to suit the military purposes and to provide application to a wide range of Army systems/equipment.

Interaction between the RCM concept, Army's ILS system and the Army's maintenance improvement programs such as, Phased Maintenance, PMCS Review, DMWR Scrub, Army Oil Analysis, etc., must also be considered. The ILS system is an effective tool for determining total support resources required during all systems/equipment life cycle phases. Further, the Logistics Support Analysis/Logistics Support Analysis Review (LSA/LSAR), a subset of Integrated Logistics Support (ILS), can be used to impact design and thereby produce the least costly logistic solutions for an operating environment. Through Appendix C, AMCP 750-16, RCM has been added to the LSA requirements and provides the means to integrate the RCM requirements to LSA, from which the Army's maintenance concept and plan evolves. Since ILS system elements are delicately balanced and are designed to enhance development of support systems which are responsive to hardware needs in either peacetime or armed conflict roles, the integrity of the ILS system must not be affected by application of RCM.

Very early in the contract period Martin Marietta researchers discovered that maintenance concepts for current fielded systems/equipment badly needed modification to provide more efficient maintenance programs but that no adequate plan existed for making the necessary modifications. It was discovered also that the Army does not have an adequate definition of RCM. It has been found that the Army's RCM concepts definition was usually interpreted as meaning RCM is "any project or program that reduces scheduled maintenance without adversely affecting equipment reliability and/or safety."

Martin Marietta thus found it necessary to prepare the following definition of RCM to provide for a common understanding of the composition of an RCM program:

> RCM is a concept for developing maintenance programs for military systems/equipment utilizing analytical methodology to determine the precise amount of maintenance and optimum distribution of tasks which are essential to preserving the inherent safety and reliability designed into the system/equipment, consistent with the lowest life cycle cost.
>
> An intrinsic part of this concept is, a) identification of all possible systems/equipment failure modes and their related consequences, b) analysis of the interaction between the failure probability and the performance of a maintenance task to detect the incipient condition or failure, and c) determination of the most effective apportionment of maintenance activities among the three classifications: hardtime, on-condition, and condition monitoring. Non-critical tasks become a part of the maintenance program only when it can be shown that to perform the task produces cost effective results.

Further, to provide grounds for effective communication with Army personnel and to provide a baseline of information for an objective evaluation of RCM programs, Martin Marietta found it necessary to prepare a comprehensive plan for improving maintenance concepts (Appendixes A and B). This plan defined the engineering analysis and decision logic that are required in any comprehensive RCM program, and contained detailed instructions and forms for conducting and recording analysis and logic decisions.

Pursuant to the objectives of the contract, six specific tasks were performed.

Task 1.0 Develop Evaluation Groundrules

Under this task the rules which the Army and Martin Marietta were to pursue (the scope of the contract) were defined. This included selecting the following commands and candidate systems/equipment for evaluation:

1 Existing Systems/Equipment

a TARCOM - M-113, Armored Personnel Carrier

b MIRCOM - TOW Heavy Antitank/Assault Weapon System

c TSARCOM - UH-1H Helicopter

d CERCOM - AN/VRC-12 Radio Set

e ARRCOM - M-110 - Self Propelled Howitzer

2 Development System Candidate

ERADCOM - AN/TPQ-37 Radar Set (Artillery Firefinder)

Task 2.0 Analyze Prior MSG-2/RCM Activities

Under this task the MSG-2 method for determining which individual tasks were necessary and at what frequency they were to be performed was analyzed, to identify what portions of MSG-2 were applicable to the Army. Details of this analysis are contained in Section 3.3.

Analyses of Navy and Air Force RCM programs were conducted, too, to determine how these services were complying with the DoD directive for the implementation of RCM, and to gain background information to be applied in evaluating the Army's compliance with the DoD directive. Details of these analyses are contained in Sections 3.4 and 3.5, and Exhibits VIII and IX.

The third analysis conducted under this task was to identify those Army programs which contain elements of RCM. This analysis is to be found in Section 3.7.

Review of the airline maintenance program was conducted at four separate airlines to determine how MSG-2 impacted the aircraft maintenance. Details of this review can be found in Section 3.6 and Exhibit VII.

Task 3.0 Analyze Army ICS/LSA/LSAR/RCM Interrelationships

Under this task Appendix C, AMCP 750-16 was analyzed to determine the impact created by its integration into the LSA procedures and in turn what influences its implementation has on ILS. Details of this analysis is contained in Section 3.8 and Exhibit XI.

Task 4.0 Evaluate Army Implementation of RCM

Under this task on-site surveys were performed at the five readiness commands and one research and development command, evaluating application of RCM on the six hardware candidates, the five existing systems/equipment, and the one development system. Programs related but initiated before RCM formalization and formalized RCM programs were evaluated in the surveys. Areas investigated included the requirements placed on the research and development and readiness commands, and their response to the requirements, contents of RCM and RCM-related programs, and the achievements in the implementation of RCM and the RCM-related programs. At the R & D command an evaluation was conducted of the ILS/LSA/LSAR as they were being applied to implement RCM. Details of these surveys can be found in Sections 3.9 and 3.10, and in Exhibits I, II, III, IV and V.

Task 5.0 Evaluate RCM Impact on Army Depot Maintenance Program

During the visits to the five readiness commands an evaluation was made to determine how depot operations were impacted as the result of implementing RCM programs on the candidate systems/equipment. The results of this effort are contained in Section 3.11.

Task 6.0 Develop Final Report

This consisted of preparing the final report, encompassing on a task by task basis all work accomplished during the contract time frame.

3.0 RESULTS OF THE ASSESSMENT AND RECOMMENDATIONS

Martin Marietta Corporation at the outset undertook the task of conducting a series of analyses and evaluations to provide the Department of the Army with an independent assessment of how well past programs have followed Reliability Centered Maintenance (RCM) principles and where benefits can be derived from present programs that have implemented RCM. Information gathered from visits to the Navy, Air Force, and the four airline facilities provided knowledge of the experiences of these organizations in incorporating the principles of RCM in their maintenance programs, to be compared with the Army's approach to RCM implementation. At the Army readiness and Research and Development Commands the data was gathered on the Army's implementation of RCM on several products. Put together, these visits provided the information necessary to perform the following analyses and evaluations:

1 Analysis of MGS-2 principles.

2 Analysis of Navy reliability-centered maintenance programs.

NOTE: Analytical Maintenance Program (AMP) is the title of the Navy's RCM program for aircraft. Maintenance System Development Program (MSDP) is the title of the application of RCM to ships.

3 Analysis of Air Force Maintenance Posture Improvement Program (MPIP), the Air Force program founded on the principles of MSG-2.

4 Analysis of industry (airline) application of MSG-2.

5 Analysis of Army program containing elements of RCM.

6 Analysis of ILS/LSA/RCM interrelationships.

7 Evaluation of implementation of RCM on fielded Army systems.

8 Evaluation of implementation of RCM on developmental Army systems.

9 Evaluation of RCM impact on Army depots.

3.1 Conclusions

Several important conclusions were drawn from these analyses and evaluations, the most important being that the Army has not developed a comprehensive RCM program for any product. Instead, Army RCM has been fragmented into a number of individual programs applied to a wide range of products. The most significant of these are the PMCS review and the DMWR scrub.

It is generally agreed that for many fielded equipment systems, in-depth RCM engineering analysis would constitute an overkill. For relatively simple equipment such as some cargo trucks, radios, small capacity generators, etc., which are allowed to run to failure (and failures are mostly due to wearout), screening the present maintenance requirements provides the most cost effective approach to RCM. Complex systems/equipment, such as fire control systems, guided missile systems, tanks, self-propelled weapons, aircraft, etc., provide the best potential candidates for systematic RCM engineering analysis and application of decision logic. These provide the most favorable returns on investment.

No matter what size or complexity, all new systems/equipment should be subjected to RCM analysis as a routine part of their individual development programs. Implementing RCM analysis as part of LSA will provide for comprehensive and effective maintenance programs consistent with the lowest life cycle cost.

The argument has been advanced from certain quarters of the Army that the present maintenance improvement programs provide the benefits equal to those realized from a comprehensive RCM program, with its engineering analysis and decision logic application. This claim can neither be substantiated nor refuted based on the available data.

One way to lay this argument to rest is for the Army to choose an item of equipment which has been the subject of the maintenance improvement program, i.e., PMCS screening, DMWR scrub, oil analysis, etc. and perform a comprehensive RCM program in accordance with the principles of MSG-2. The results of the two programs could then be compared to determine which approach is most desirable and fulfills the DoD requirement for RCM implementation.

There has been a serious lack of RCM instructions and guidance provided to the Readiness and Research and Development Commands concerning the implementation of RCM. Those instructions that have been published have been the subject of numerous interpretations.

Expertise required to develop Failure Mode Effects Analysis (FMEA) is not available within the Readiness Commands. Faced with a similar situation the Air Force, and to some extent the Navy, solved the problem by contacting for this service.

In the instances where decision logic has been employed the logic has been narrow in scope, offering only limited possibilities to reduce maintenance costs. The logic questions have also demonstrated intrinsic complexities which can result in multiple paths or which require decisions

based on intuitive judgment. Logic questions which are designed to be answered in a simple, straightforward manner, that is, which are limited to "yes" or "no" answers, are preferable.

The Army's approach to maintenance planning has resulted in a number of individual programs, which the Army termed RCM, i.e., PMCS screening, DMWR scrub, On-Condition Depot Maintenance Selection, etc., applied over a wide range of products. This is unlike the Navy and Air Force, which have developed their RCM programs by products. In their programs early engineering analysis was performed to establish the maintenance-significant item, failure mode and effects, fault detection and location procedures. Decision logic was used to define the maintenance tasks. The Navy and Air Force approach resulted in generating a total RCM maintenance program for its products, whereas the Army's approach results in only partial revision of the present maintenance programs.

The Army's RCM training program is not reaching the people who are responsible for performing the day to day task of fulfilling the RCM requirements. The majority of people contacted, at the working level, had a misconception of the concept and principles of RCM. There has been inadequate dissemination of RCM information to the working level by trained personnel.

In AMCP 750-16, Appendix C, the Army has integrated RCM into LSA with a minimum of change to the LSA program. The results of this integration should ensure that RCM concepts will influence the content of the maintenance plan during the early phases of system development and the maintenance program as it is generated. However, the effectiveness of RCM in the development of the maintenance program for any new product is totally dependent on LSA and a Failure Mode Effects and Criticality Analysis (FMECA) being specified as a requirement. A number of cases can be cited where in the procurement of new systems/equipment LSA requirements have been curtailed and the requirement for the FMECA has been reduced or eliminated due to cost considerations. There are no alternate methods for ensuring the generation of an RCM program when either or both LSA and FMECA are curtailed or eliminated. Without these two elements there can be no RCM program implemented during the development phase. The alternate, which is totally unacceptable, is to wait until the system/equipment has been fielded for several years and, using the field maintenance data, implement an RCM program in accordance with the procedures for a fielded system.

The Navy's approach to the implementation of RCM on its aircraft has merit for application to the Army's aeronautical and non-aeronautical equipment. The key elements of the Navy's RCM program, covered in paragraph 3.4, below, are worth adapting by the Army.

None of the four airlines surveyed, the Navy or the Air Force has developed an adequate method for assessing cost benefits resulting from maintenance program changes. Avoidance costs resulting from deleting maintenance tasks are easily accountable. It is when procedural changes

are incorporated into the program that the cost benefits become elusive. Also, the fact there is no distinct demarcation between the period of conventional maintenance and the period of RCM maintenance adds a handicap to measuring cost benefits.

Non-aeronautical systems/equipment maintenance information, such as RAM data and field maintenance cost data, required in the decision-making process of RCM program development and for evaluating the RCM program once it has been implemented were found to be nonexistent or were so fragmented that their value was suspect. For aircraft this data is available and has been used in developing maintenance programs using the MAVIS model. The effectiveness or the sustaining phase of an RCM program is directly related to the quality of the available maintenance data.

The MAVIS model is not an RCM decision-making model but is an analysis tool which could be used for optimizing on-condition or hard-time inspection plans once the RCM decision process has determined which plans are applicable. To use the MAVIS model, though, certain RCM data and a candidate phase inspection plan must be input to provide output as to the cost and effectiveness of the candidate plan. This is within current Army capability.

3.2 Recommendations

3.2.1 Fielded Systems/Equipment

It is recommended that DARCOM review available RCM documentation and upgrade information to RCM activities throughout all commands. Key elements of the Navy's AMP for RCM implementation should be considered, as well as the return on investment experienced by the Air Force from application of MPIP to Communications, Electronics, Meteorological/Aircraft Support Equipment (CEM/SE) systems. Martin Marietta Corporation recommendations for RCM program development (Appendixes A and B to this report) provide a step-by-step procedure that is directly applicable to Army RCM enhancement. Listed below are the recommendations that appear appropriate to resolve the problems noted in the above conclusions. Specific recommendations on each system/command surveyed are contained in Exhibits I through V.

1 Develop and publish a formal RCM definition that is positive in purpose and which adequately defined basic elements. This definition should include measureable goals anticipated and should require specific procedures.

2 Develop complete and thorough guidance, accompanied with adequate instructional courses, for the benefit of the readiness command working level personnel, to eliminate interpretation differences, lack of understanding, and the confusion that has characterized RCM implementation efforts to date.

3 Provide the resources needed by readiness commands to accomplish the technical and disciplined engineering analyses that are essential to development of RCM-oriented maintenance programs. If personnel expert in such activities are not available contractor assistence should be considered.

4 Support the acquisition and enhancement of accurate, dependable, and useful field operating and maintenance data to provide a solid, provable basis for performing engineering analysis (FEMA/FDLA) on all systems considered to be RCM-applicable. Where actual field experience is not available sample data collection tests should be funded to provide a firm data base.

5 Develop a methodology for preparation of FMEA and require its use in all RCM efforts on systems/equipment which will provide a good review on investment. For appropriate items Fault Detection and Location Analysis should accompany the FMEA. If a FMEA is not feasible, a suitable alternative should be substituted for RCM purposes.

6 Require development of RCM decision logic diagram and narrative explanations of questions designed for each type of system, and require their use. The logic used should be broad in scope and comprehensive, and stimulate creation of maintenance improvements. The RCM analyst team should include personnel from organization level maintenance of an operational unit.

7 Develop a complete and comprehensive RCM program for at least one major weapon system in each command, using all resources available to resolve problems. This program should be thoroughly documented as a model for similar systems.

8 Document all of the RCM-related programs which have demonstrated success in meeting the RCM primary objective or which reasonably can be assumed successful if supporting data is obtainable, and retain them as reference for further efforts.

9 Sponsor the development and identification of new techniques in fault detection and isolation, particularly in electronic equipment, to further reduce future maintenance expense.

10 Require the generation of documentation and development of audit trails to support tracking of RCM processing and correlation of maintenance decisions with supporting field or test experience data as a means of evaluating the effectiveness of RCM.

11 Require establishment of a sustaining engineering phase as a permanent function of each readiness command RCM effort, including continuous monitoring of field failure experience and subsequent failure analysis.

12 Establish the policy that future modification to RCM planning should be developed systematically and promulgated logically, that is, identify the problem, describe the background, consider solution options, select the best solution, establish the requirements of this solution, determine the best dissemination method, prepare in-depth guidance, develop instructions for a procedural approach, publish the plan, assign organizational responsibility for accomplishment, and require feedback to monitor effectiveness.

13 Eliminate confusion and misunderstandings by revision of RCM terminology e.g., on condition maintenance (vehicle overhaul selection), on-condition (RCM maintenance task), and condition monitoring could be redesignated as Analytical Condition Evaluation (ACE), sequential or repetitive service (SS or RS), and equipment monitoring (EM), respectively.

3.2.2 Developmental Systems/Equipment

1 Select a system currently in advanced or early engineering development stage and evaluate RCM incorporation into the LSA requirement per Appendix C to AMP 750-16.

2 When RCM is a requirement LSA and FMECA must be contractual requirements. To assure that these items will not be curtailed or eliminated, the movies to perform these tasks must be dedicated (fenced) for that purpose only.

3 Require that RCM sustaining engineering phase be established for new systems/equipment during the development phase and continue through the life cycles of the product. This provides the means of evaluating RCM in both the test and operational phases.

4 The implementation of RCM on the fire finder (AN/TPQ-37) has produced unsatisfactory results. To correct this RCM should be applied to the AN/TPQ-37 by application of RCM in accordance with the procedure for fielded systems.

3.3 Analysis of MSG-2 Concept

The special purpose of the airline/manufacturer maintenance program planning document, MSG-2, is to present a means for developing cost effective maintenance programs for commercial aircraft which will be acceptable to the regulatory authority (FAA), aircraft operators (airlines), and the aircraft structure and power plant manufacturers. Specifically, the document outlines organization and decision processes for determining essential scheduled maintenance programs for new aircraft. Its intent is to facilitate the development of initial scheduled maintenance programs that historically have been specified Maintenance Review Board (MRB) documents.

The MSG-2 method for determining which individual tasks are necessary and how frequently these tasks should be scheduled employs engineering analysis and decision logic diagrams. The diagrams are the basis of an evaluatory process applied to each aircraft system and its significant items, using specific technical data as input. Principally, the evaluations are based on the systems' and items' functions, failure modes, and consequences. Their purpose is to:

1 Identify the systems and their maintenance significant items

2 Identify their functions, failure modes, and failure consequences

3 Define scheduled maintenance tasks having potential effectiveness relative to the control of operational reliability

4 Assess the desirability of scheduling those tasks having potential effectiveness

Output from the three decision-tree logic diagrams provide:

1 Identification of scheduled maintenance tasks having potential effectiveness relative to the control of operational reliability

2 Selection of tasks done because of safety or hidden function considerations

3 Selection of tasks done because of economic reasons.

MSG-2 has been developed to be used exclusively for the development of maintenance programs for aircraft structures and power plants. Therefore, MSG-2 in its present form is not directly applicable to any other type of systems/equipment. To apply MSG-2 procedures to other products it is first necessary to restructure the decision logic and to redefine the input data requirements.

Martin Marietta investigators recognized the limitation of MSG-2 in developing maintenance programs for other-than-aircraft structures and power plants. The Martin Marietta team therefore developed a plan for improving maintenance programs for existing systems/equipment (Appendixes A and B). This plan uses the airline industry's MSG-2 concept as a foundation, with additional flexibility incorporated to provide the capability for applying it to a wide range of military systems/equipment. It is not intended as an absolute inviolable instrument for implementation, but a general approach to adapting the MSG-2 concept in developing maintenance program improvements. By changing or eliminating certain questions the Martin Marietta plan can be tailored to meet the requirements for developing a maintenance plan for any military system/equipment.

The Martin Marietta plan has been titled "Reliability Centered Maintenance" because it meets the Army's requirement for a method of developing a maintenance program which has as its intended purpose the preservation of inherent safety and reliability of a system/equipment through proper maintenance at minimum practical cost.

In developing the RCM plan to improve maintenance programs for existing systems/equipment the following requirements were kept in mind:

1 The RCM plan must be capable of being applied to numerous systems/equipment, must be specific in its contents, must recognize a broad spectrum of conditions affecting maintenance performance, and must prove to be cost-effective.

2 The development of an RCM plan for existing military systems/equipment requires many logic decisions pertaining to: 1) individual requirements that are necessary, 2) the scope and frequency in which these requirements should be performed, and 3) their impact on maintenance and support. Military applications require that the program be capable of application to a large variety of systems/equipment and at the same time be adaptable to the specific requirements of any individual systems/equipment.

3 The RCM plan must cope with all systems/equipment, whether of simple or complex nature, which have a multiplicity of uses, which may be employed in numerous and varying environments, which may have a requirement to be maintained in constant peak performance condition, and which must be capable of responding to emergencies with minimum or no maintenance. It is desirable that the resulting RCM maintenance program should result in a cost saving when compared with the present maintenance program.

4 The RCM plan should result in a maintenance program so constructed as to reduce and minimize the numerous outside influences which can affect the efficiency of the program.

When the RCM approach is applied to any Army systems/equipment the result will be the creation of an RCM program, tailored specifically for that item of hardware, which will prevent deterioration of the inherent design levels of reliability and operating safety.

3.4 Analysis of Navy Reliability Centered Maintenance Programs

Martin Marietta conducted a survey at three Navy facilities. The Naval Rework Facility, Jacksonville, Florida, was visited to review the application of RCM on the Navy's A-7 aircraft. At the Naval Aviation Integrated Logistic Support Center, the discussion was mainly concerned with an overview of the policies and procedures concerning RCM implementation to aircraft. At the Naval Sea Systems Command, implementation of RCM on surface ships and ship support delivery systems was the subject.

All Navy programs are comprehensive in scope and make use of engineering analysis and decision logic based on the MSG-2 concept. A detailed description of the Navy's RCM program is contained in Exhibit VIII, "Navy RCM Survey Report."

Key elements of the Navy's RCM program are fundamental to the implementation of any RCM program. The most important elements are:

1 Emphasis on the importance of the failure mode and effects analysis as the heart of RCM.

2 A three phase approach: analysis phase, implementation phase, and sustaining engineering.

3 Decision logic to dictate needs of the hardware.

4 Analysis by personnel with detailed knowledge of the system.

5 Contact operational and maintenance personnel at all levels prior to the development of a program for an existing system.

A complete listing of all key elements can be found in the Exhibit VIII, "Navy RCM Survey Report."

Although these points were brought out in the Navy's application of RCM to aircraft, they are equally well suited to any product. Evidence indicates that they are being incorporated into Navy's RCM program philosophy for non-aeronautical products.

Early in its RCM program for aircraft the Navy issued several documents which provided the necessary guidance for those implementing the program. A listing of these documents can be found in the Exhibit VIII.

The Navy has titled its approach to implementation of RCM on aircraft, Analytical Maintenance Program (AMP) and its application to ships Maintenance System Development Program (MSDP).

The Navy's Analytical Maintenance Program (AMP) parallels and draws from the MSG-2 approach. It uses engineering analysis and logic decision process to justify individual maintenance requirements. Only those maintenance tasks which are required to prevent deterioration of the inherent design levels of reliability and safety or provide an economic value are scheduled. The strategy behind AMP is divided into three groupings:

1 Establishment of a formalized and fully documented analysis procedure to logically determine the maintenance program requirements. The planning is patterned after MSG-2.

2 Performance of only those tasks that are necessary to retain the inherent design levels of reliability and safety.

3 Provide a sustaining, monitoring and updating function coupled with the appropriate data collection to ensure that the overall analysis is accomplished in an optimum manner and is updated and revised as service experience may dictate.

The early results from the first aircraft (P-3) to complete this process show significant benefits. The P-3 program resulted in substantial reduction in scheduled maintenance manhours per flight hour (21 percent reduction in P-3 scheduled maintenance, at both organizational and intermediate levels and a 15 percent reduction at depot level), and a significant increase in the prescribed depot rework interval (P-3 goes into depot for overhaul every 5 years instead of the previous 3 year cycle).

Under direction of the Ship Support Improvement Project Manager the Maintenance System Development Program was established to improve ship maintenance and to attain and maintain a realistic level of ship availability at the lowest cost.

The Navy's Maintenance System Development Program (MSDP), like the AMP, parallels and draws from the MSG-2 approach in applying analytical thinking to development of ship maintenance programs. Unlike the AMP the MSDP is just beginning to get underway.

To achieve the MSDP objectives, four steps were identified:

1 Through research and analysis, develop a thorough understanding of the structure and functions of the present Navy maintenance system, and create an ideal ship maintenance program.

2 Identify major problems in current maintenance processes and develop alternatives leading to least-cost recommendations that will improve system operation sufficiently to achieve a specified level of availability.

3 Draw up plans and procedures for demonstrating the results of the applied methodology.

4 Propose the institutional arrangements for continuing research development, and implementation of improved maintenance management practices.

In accordance with these steps, procedures for developing a shipboard RCM scheduled maintenance program will be prepared. This set of procedures will provide the qualified maintenance engineer with a rigorously disciplined set of instructions to be followed.

Specific objectives in the development of the shipboard scheduled maintenance program should:

1 Define logic which adapts RCM principles to warships

2 Develop a methodology which applies that logic

3 Accomplish and document required analyses in accordance with the developed methodology

4 Produce a draft set of Maintenance Requirements Cards (MRC) and PMS Schedules

5 Produce a procedure for developing a shipboard scheduled maintenance program, as derived from defined program logic and procedures

6 Plan and execute a prototype demonstration of procedures.

The survey at the three Naval facilities has produced the following significant information in regard to the Navy's implementation of RCM. Development of the RCM program for the A-7 required nine engineers for 15 months, in addition to which a contract in excess of $100,000 was awarded to the aircraft manufacturer to provide failure mode and effects data. Most of the failure mode and effects analysis performed by the

aircraft manufacturer had to be discarded. The analysis was based solely on theoretical data generated at the time of the aircraft design and not borne out subsequently by applied data. RCM program for existing systems/ equipment should be based on data collected during actual operations and maintenance. If data are not available, the theoretical data should be recomputed, incorporating available actual experience. In some cases the system and subsystem level hardware should be applied to the decision logic along with the maintenance significant items (components).

After the RCM program was implemented on the A-7, confining the maintenance effort to items authorized at any given interval was a problem. The mechanics were inclined to perform more tasks than were authorized. This was particularly true at the depot level where, in the past, mechanics performed extensive rework each time the aircraft was brought in. As a result, two levels of training were provided. One training course was structured for the maintenance personnel and the other for management personnel. These courses went a long way in gaining acceptance of RCM, by the working groups.

As a result, two levels of training were provided. One training course was structured for the maintenance personnel and the other for management personnel. These courses went a long way in gaining acceptance of RCM, by the working groups.

Navy personnel were familiar with the MAVIS model and its application by the Army (TSARCOM). They doubted the effectiveness of the model to provide the data needed in the construction of an effective RCM program. There were no plans for utilization of the model by the Navy.

In 1976 the Office of the Secretary of Defense directed that the scope of Reliability Centered Maintenance be expanded to cover all military vehicles. In compliance, the Navy awarded a contract to American Management Systems Incorporated (AMS) to perform extended studies, particularly of the Navy organization for maintenance of ships and of ship support delivery systems. In turn the Lockheed California Company (LCC) was awarded a subcontract by AMS to develop a methodology based on RCM concepts for determining the scheduled maintenance requirements of surface ships.

In March 1978, LCC delivered to the Navy a manual which contained the procedures for the adaption of RCM principles to shipboard scheduled maintenance. These principles involve the application of decision logic, failure mode and effects analysis, maintenance task analysis and maintenance program development.

In developing the RCM program for the FF-1052 class ship, considerable problems have been encountered as the result of the Navy not having purchased MIL-SPEC documentation for the critical components of the ship. NAVSEASYSCOM personnel have pointed out that they share a common problem with the Air Force and Army in that DoD guidance has not been adequate to accomplish the RCM implementation test.

3.5 Analysis of Air Force Reliability Centered Maintenance Programs

Martin Marietta conducted a survey at three Air Force facilities. The visit to Headquarters, Air Force Logistics Command, was to obtain an overview of Air Force's approach to RCM implementation. At Sacramento Air Force Logistics Center the discussion was concerned with the application of RCM to Communications/Electronics/Meteorological and Aircraft Support Equipments. The main topic of discussion at Warner Robins Air Force Logistics Center was the Benefit Assessment Program Plan for the C-141 Airplane.

Like the Navy programs, Air Force RCM programs are comprehensive in scope and use both engineering analysis and decision logic. Their RCM programs for aircraft also parallel and draw heavily from MSG-2.

The Air Force's implementation of RCM to aircraft was done under its Maintenance Posture Improvement Program (MPIP). In most instances of RCM implementation, the Air Force contracted with the prime airframe manufacturer to perform engineering analysis and establish the RCM program for their product.

All RCM programs implemented to date on aircraft are comprehensive in scope and consist of system and component function and failure analysis and the use of decision logic to determine the maintenance requirement for each maintenance significant item. System and components analysis results in identifying systems and their significant items, functions, failure modes and effects; scheduling maintenance tasks having potential effectiveness relative to the control of operational reliability and safety; and in assessing the desirability of scheduling those tasks having potential effectiveness in restoring the inherent design level of reliability and safety. When a component failure does not reduce flight reliability or safety, the decision as to whether a maintenance task is desirable is based on economic factors and is determined through an effective tradeoff between cost and the task benefit. The analysis provides the final judgement as to whether there are tasks worth including in the maintenance program.

The Air Force has established a Reliability Analysis Center to track and evaluate RCM programs. To aid the centers in this effort a computer program labeled SMFOP has been developed. SMFOP stands for Scheduled Maintenance Frequency Optimization Program. It is a mechanized Exception Report type computer program designed to aid maintenance managers in keeping inspection programs updated to reflect aircraft inspection needs. The program will:

1 Identify equipments that are not being inspected but should be

2 Identify failure modes that should be added to the inspection requirement

3 Identify failure modes that should be deleted from inspections

_4_ Identify inspection interval changes for discrete tasks

_5_ Identify interval changes for computer packages.

The results obtained by the implementation of RCM on the B-52 are typical of those being experienced on other aircraft. B-52 maintenance processes have been impacted in the following ways: the 35 hard time tasks were reduced to 17, while the 225 on-condition tasks and 1,947 condition monitoring tasks were reduced to 241 and 948.

Present Air Force plans call for RCM implementation on missiles, communications/electronics/meteorological (CEM) and aircraft support equipment (SE) beginning in FY 78. The Minuteman missile has been exempt from the application of RCM, since it is constantly condition monitored when on-station.

A Producibility, Reliability, Availability and Maintainability (PRAM) project has been approved for a three-phase program for applying RCM to CEM/SE.

Under Phase I, the CEM/SE data systems and maintenance organizations have been surveyed, and the methodology developed under the MPIP studied for further adaptation to suit these equipment, data, and organizations. Under Phase II, a set of representative CEM/SE are selected for trial application of the newly developed methodology, and the criteria for selecting analysis candidates are developed. If the trial applications under Phase II demonstrate an adequate return on the Air Force investment, Phase III will be initiated. This will provide for application to all qualified CEM/SE in the inventory.

With completion of Phase I effort, the contractor recommended the Phase II effort for CEM/SE be implemented, with the following limitations:

_1_ Apply the MSG-2-type analysis to CEM equipment only.

_2_ Select trial equipment from the following list of candidate categories, to include:

_a_ Air-ground UHF/VHF radios

_b_ TRACALS radars

_c_ TRACALS navigational aids

_d_ Weather instruments.

_3_ Apply the newly-developed methodology only to operational equipment.

_4_ Assess the adequacy of data gathered through field surveys for analyzing significant equipment failure modes, via a formal FMEA or similar depth of analysis.

5 Use information from existing AF maintenance data systems to evaluate the efficiency of new Preventive Maintenance Inspections (PMI) relative to old PMI.

6 Develop a method for selecting candidates for analysis, using selection criteria such as equipment cost, population, mission essentiality, deployment environments and sites, and scheduled and unscheduled maintenance costs.

The contractor also recommended that the Air Force require all manufacturers of new equipment to apply the MSG-2 type logic process when preparing recommended preventive maintenance requirements.

Using the C-141 aircraft as a test case, an Air Force plan has been developed for assessing the benefits accrued from the RCM program implemented in June, 1977. In establishing this assessment plan, the Air Force Logistics Management Center decided that RCM was not to be used for manpower determination. Manpower would continue to be established using standard methods. The RCM assessment is thus primarily restricted to the use of in-place data systems. As a result, the majority of indicators available for RCM assessment were not designed for that purpose. Indicators were selected that were most likely to reflect the RCM impact on operations and maintenance.

Since the Benefit Assessment Program plan has been structured for aircraft, and since manpower is not an item of assessment, this program plan has little to offer the Army for assessing RCM impact on non-aeronautical items.

3.6 Analysis of Airline Industry Maintenance Programs

Martin Marietta conducted a review of maintenance programs at four separate airlines: Frontier, United, Eastern, and Flying Tiger Lines. Each was selected for some unique reason. Frontier was selected for its route structure, and its environmental impact on maintenance requirements; United Airlines, because its personnel were in the forefront of creating the MSG-1 and MSG-2 maintenance concepts; Flying Tiger Lines, because of its unique type of operations; and Eastern Airlines, because it had reportedly discarded the MSG-2 concept.

Maintenance programs for new aircraft are established during the development phase through a cooperative effort of aircraft manufacturers, the airlines, and the Federal Aviation Authority, using MSG-2 engineering analysis and decision logic. The result of this cooperative effort is a maintenance program that is binding on the aircraft operators for a period of one year. After that, the operators may modify the maintenance program with FAA approval.

Although the MSG concept is used to generate the maintenance program, the airlines are not compelled to use it. Neither Frontier nor Flying Tiger Lines has found it convenient to employ the MSG-2 maintenance concept. United Airlines, however, makes extensive use of the MSG-2 concept in performing maintenance planning, even with its avionics equipment. Unlike the other major airlines, United has a large engineering staff and an extensive data processing capability which provide the resources to implement MSG-2. United's Director of Maintenance Analysis, Dr. Stanley Nowlan, was awarded the 1977 AIAA System Effectiveness and Safety Award for his contribution in conceiving and developing the decision-tree-oriented approach to aircraft maintenance program design known as MSG-1 and MSG-2.

Eastern Airlines applies a sort of loosely-organized MSG concept when developing changes to its maintenance program. The decision logic may vary from item to item and there is no formal documentation system to track the results of MSG-2 logic decisions.

Changes to the maintenance program are usually made to increase the maintenance interval, or to upgrade the maintenance program. When Eastern desires a maintenance program change or wants to investigate a possible program to determine the unknown, this information and other data are applied to the MSG-2 process to establish what the revised maintenance tasks should be. Eastern has applied the MSG-2 philosophy in numerous cases to shift the maintenance from on-condition to condition monitoring.

Eastern's spokesman stated that the line has not found a good way to quantify the cost benefits resulting from incorporation of maintenance program changes. A United spokesman said that although the implementation of MSG-2 philosophy has resulted in a marked reduction of scheduled maintenance costs, due to the deletion of unnecessary and ineffective tasks, it is somewhat difficult to identify the actual cost reduction.

3.7 Army Programs Containing Elements of RCM

3.7.1 Background

In accordance with the requirements of Task 2.0, subparagraph c, Martin Marietta conducted research to identify those Army programs which contain elements of RCM. Certain programs closely allied to, or which in some way affect those RCM-related programs, were also examined. Table I, Interrelated Programs, contains a listing of the RCM-related programs, and those programs that are interrelated with them in one manner or another. Included in Table I, for reference purposes only, are MSG-1 and MSG-2, since they are considered as the basis for RCM.

TABLE 1
Interrelated Programs

	Authority of Reference	Organization Affected	Applicability	Test	Impl. Date	Program Objective	Remarks
MSG-1	Air Transport Assoc. and FAA	Commercial Airlines	747		1968	Reduction of maintenance cost without affecting safety and reliability	The advent of the larger jets required more efficient maintenance programs
MSG-2	Air Transport Assoc. And FAA	Commercial Airlines	All Inservice aircraft		1970	Same as MSG-1	Extended the MSG-1 concept to all inservice aircraft
SAMS	LOGMAP Vol. I Objective 200	Using Units to HQDA	All Army Equipment		1974	An automated maintenance management system	Standard Army Maintenance System
LSA	AMCP 750-16 Mil. Std. 1388	Equipment Development Contractors	All New Equipment			To provide complete and uniform maintenance planning	Logistic Support Analysis - replaced maintenance engineering analysis
ILS	DoD 4100-35	Equipment Development Contractors	All New Equipment		1967	Achievement of proper balance between operational, economic and logistic factors	Integrated Logistics Support
AOAP	AR 702-1 AR 750-13 (AMC Suppl. #1) AR 750-22 TB 43-0210	Using Units and Maintenance Support Units	Aviation Equipment Non Aeronautical Equipment		1957 1975	To determine the internal physical condition of engines, gearboxes, transmissions, etc.	Army Oil Analysis Program - Army aircraft first placed under program. Based on test results, III Corps recommended extending program to non-aeronautical equipment (1974). DA approved the recommendation and in 1975 directed AOAP be extended to other equipment.
OCM	Memorandum from Office Asst. Sec. Army. 15 June 76 DA letter HQDA letter 750-16-3.	Using Units and Depot Maintenance Organizations	Aviation Equipment Tracked and Wheeled Vehicles		1973 1976	To provide a more realistic peace time overhaul criteria	On-Condition Maintenance - concept developed by TSARCOM for Army aircraft. Extended to track and wheeled vehicle in 1976. TSARCOM found it necessary to revise aircraft DMWRs to be compatible with OCM.
3 LEVEL MAINTENANCE	LOGMAP Vol. I Objective 202.i	Using Units, Maintenance Support Units and Depot	Aviation Equipment		1974	To develop a more effective and efficient Army aircraft maintenance support structure	Presently limited to aviation maintenance.
PROJECT INSPECT	LOGMAP Vol. I Objective 202.k	Using Units	Aviation Equipment	CH-47 and UH-1H 1973/75	1976	To provide using units with an improved aircraft inspection scheme	Heart of concept is the development of aircraft checklists based on failure rates with emphasis on failure onset detectability to optimize aircraft availability.
LEAP	DA ltr. DACO-PLD dtd. 21 April 1975	Using Units and Maintenance Support Units	Combat Equipment Authorized to Division Forces		1975	Determine those maintenance requirements which are vital to maintaining readiness	A review of scheduled maintenance requirements described in the current technical manuals.
RCM	DoD POM 80-82 DA letter HQDA Ltr. 750-76-3 DA letter HQDA Ltr. 750-77-1	All Army Research and Readiness Commands	Fielded and Developmental Systems/Items		1976	Develop and formalize equipment maintenance strategy by incorporating the principles of MSG-2	Reliability Center Maintenance
ESC ELIMINATION	DA letter DACO-SMM-F dtd. 12 Feb. 1976 DARCOM letter DRCMM-MP dtd. 2 June 1976 DARCOM message 03-2030z dtd. March 1978	Using Units	Fielded Equipment		1976	To achieve improvement in the reliability and utility of the information reported on equipment	Equipment Serviceability Criteria
PMCS Review	DA letter DACO-PUD dtd. 21 April 1975 DARCOM letter AMCMA-SE dtd. 13 Aug. 1975 DA letter DACO-SMM-F dtd. 12 Feb. 1976	Using Units	Fielded Equipment		1976	To reduce or eliminate those checks and services having marginal value	Preventive Maintenance Checks and Services Replaced project leap.
DMWR Scrub	DA Message DA 04 2225z dtd. Feb. 1977 SAR(u) DARCOM Message R22 2209z Feb. 77	Maintenance Depots	Fielded Equipment		1977	Review and revise the DMWRs to achieve compatibility with RCM	Depot Maintenance Work Requirements
Rise	AMC Regulation 702-15	Readiness Commands	Selected Equipment		1976	RAM improvement through equipment redesign to reduce life cycle maintenance costs	Reliability Improvement of Selected Equipment
ITDT	DARCOM Message DRCMM 22 1722z 76	Training and Documentation Command	-		1976	To provide simplified instructions for self-paced training and maintenance procedures	Integrated Technical Documentation and Training

The Army's approach to RCM has been to consider some ongoing maintenance concepts, such as oil analysis and on-condition maintenance (selection of aircraft for overhaul), as being capable of achieving reliability-centered maintenance objectives. In addition, the Army has introduced such programs as Preventive Maintenance Checks and Services (PMCS) review and DMWR Scrub as RCM programs. While it is true that each contains or results in some element of RCM, they fail to meet total requirements as set forth in MSG-2, Airline/Manufacturer Maintenance Program Planning Document, which is the basis from which RCM was developed.

MSG-2 requires engineering analysis and the use of decision diagrams. These are the basis of the evaluation process applied to each system and its significant items, using technical data inputs. The evaluations are based on system and item functions and failure modes. The purposes are to:

1 Identify systems and significant items

2 Identify functions, failure modes, and failure effects

3 Define scheduled maintenance tasks having potential effectiveness relative to the control of operational reliability

4 Assess the desirability of scheduling those tasks having potential effectiveness.

The Army's approach to RCM has been to review the preventive maintenance checks and services presently contained in the operators' manuals and to review the depot maintenance tasks presently contained in the Depot Maintenance Work Requirement publication.

Presented below are brief descriptions of programs which contain elements of RCM, and those which have been identified as mutually supporting programs.

3.7.2 Standard Army Maintenance System (SAMS)

Purpose: Provide a standard maintenance management system to support the material maintenance function at all levels of the Army Logistic System.

SAMS can be used as the vehicle for obtaining the information needed to gauge the effectiveness of RCM, and to correct any imbalances in the RCM program.

In developing the sustaining phase of the RCM program, serious consideration must be given to interfacing RCM with SAMS, using SAMS as the source for obtaining RCM data.

SAMS identifies maintenance functions and essential elements of information required to manage these functions at all levels of command, from using units to Department of the Army. The system provides functional procedures and associated software programs to meet managerial requirements at each level of command. The system is vertically integrated and interfaced. This ensures standardization and permits rapid communication between management levels. The system is horizontally integrated, and will interface with other related subsystems such as supply, transportation, facilities, finance and personnel. It identifies four levels of maintenance management - Department of the Army (national level), Maintenance Program Management (MPM), Maintenance Program Operation Management (MPOM) and Maintenance Operation Management (MOM). User level maintenance operations and reporting requirements are a part of the MOM level.

SAMS objectives are directed at achieving an automated maintenance management system based on the following three basic concepts:

a The computer will perform the major portion of the management analysis and provide the manager only that information which is essential to the performance of his job.

b Maintenance management information responsive to the needs of both field commanders and the national level will flow vertically through the various echelons of command.

c Two types of data will flow through the system:

Maintenance Operations Performance Data, consisting of information on the use and application of the work force, funds, and industrial equipment to sustain weapon and end item systems in an operational status. These data flow both horizontally (intra-organization for control) and vertically (down as well as up for guidance and performance measurement).

Equipment Performance Data, consisting of historical information relating to maintainability, reliability and supportability characteristics of weapon and end item systems accumulated during their operational application. These data generally flow from the lowest level in the maintenance support structure to the Material Development Commands/Agencies designated collection point. They must be generally restricted to Sample Data Collection techniques on an as-required basis from selected units.

3.7.3 Logistic Support Analysis

Purpose: Provide a method for complete and uniform development of logistic support elements and provide the interface between the hardware design and Integrated Logistic Support programs.

AMCP 750-16, Appendix C, revises the LSAR "B" sheet by adding the appropriate blocks to record the output of the RCM decision logic application. From the completed "B" sheet, information will be available to

generate the maintenance plan, based on RCM principles, during early stages in the development of the system/equipment. See Section 3.8 for detailed relationship of ILS/LSA/RCM.

The LSA program has four primary objectives: identification, logistic influence, communications, and verification.

The analysis identifies the qualitative and quantitative logistic support requirements. A systematic, comprehensive analysis is conducted on an iterative basis throughout the life cycle. Initial analyses evaluate the system/equipment's design and operational parameters and translate them into a maintenance concept and estimated support costs. During the development phase, maintenance tasks are defined and logistic support requirements are identified. During the operational phase, proposed design changes and modifications are evaluated to identify their effect on maintenance and support.

The analysis influences the system/equipment design for logistic considerations. The initial analysis effort evaluates the effects of design alternatives on support costs and operational readiness. Known scarcities, constraints, or logistic risks are identified and ways of overcoming or minimizing them are developed. During full-scale development the analysis is oriented toward assisting the designer in improving supportability and ease of maintenance.

The analysis communicates requirements and integrates the elements of logistic support into a logistic support system. The LSA program establishes a communications link between the hardware design and ILS functional organizations through the Logistic Support Analysis Record (LSAR). The LSAR is a source of validated design-related logistic data. The inputs to the LSA process are mission, performance, and environmental requirements; maintenance, supply, and personnel policies; economic criteria; training capabilities; existing skill capabilities; available Government-furnished materiel/equipment; and, maintenance concepts. The LSAR communicates the logistic support requirements and is a source of data for the system/equipment design effort. It is in the form of suggestions for improving the reliability, maintainability, supportability, and ease of maintenance. The LSAR provides data for risk analyses, effectiveness studies, design/logistic support tradeoffs, and life-cycle cost analyses.

Testing verifies the supportability of the equipment and validates achievement of logistic goals. Progressive ILS testing is part of the overall development and operational testing. This ILS testing verifies supportability features such as accessibility and support system compatibility, and validates the adequacy of the publications, facilities, support equipment, repair parts, and personnel skills. Deficiencies are identified by comparing the test results with the LSA data.

The LSAR is a medium for systematically recording analysis data. Recording sheets are identified alphabetically, A through H. The LSAR may be used on any program, regardless of size or complexity. The formats and data element definitions may be amended, supplemented, or altered with procuring activity approval, to tailor them to program variations. The

procuring activity must specify which data elements are required for the particular application.

3.7.4 Integrated Logistic Support

Purpose: Achievement of the proper balance between the operational, economic and support resources throughout the life cycle of an end item or system.

The RCM information will be extracted from the LSAR "B" sheet to be used in the generation of the system maintenance plan. Therefore, ILS, LSA and RCM are all interrelated in developing logistic support requirements, from inception of first ideas through design, development, production and field use. See Exhibit XI for a detailed description of the ILS/LSA/RCM relationship.

Integrated logistic support is realized through the proper integration of its elements, (maintenance planning, supply support, facilities, technical data, personnel and training, support and test equipment, transportation and handling, maintainability and reliability, funding, and management data) with each other, and through the application of logistic considerations to hardware design decisions as part of the system engineering process.

The ILS concept embraces all resources required to operate, maintain and support a system in the field. The material resources are directly related to the design of the system to be supported. For this reason, the integrated logistic support concept provides for an analysis of new material design. This is done to decrease and simplify the planned support requirements in the system design and to achieve:

1 Early consideration of support requirements in design and development of new systems

2 Improvement of maintenance support and reduced skill requirements

3 Improved correlation, traceability and integration of data elements related to support

4 Better definition and expression of work requirements associated with planning and development of support

5 More timely and adequate support available for system during tests and at the time of initial issue.

Applying RCM engineering analysis and decision logic to develop the maintenance plan early in the acquisition cycle will have a pronounced influence on the remaining logistic elements. It will result in performance objectives being backed by achievable material support at low life cycle costs.

3.7.5 Army Oil Analysis Program (AOAP)

Purpose: AOAP is a coordinated Army-wide effort to detect impending equipment component failures through analytical evaluation of oil samples. It was formerly referred to as the Army Spectrometric Oil Analysis Program (ASOAP).

Oil analysis can be considered a task in reliability centered maintenance programs. Periodic testing of oil samples is an on-condition maintenance action.

Oil analysis is a test or a series of tests to provide an indication of equipment condition by applying a method of precision detection and quantitative measurement of wear metals in an oil sample.

An important part of the premature failure detection system is the spectrometric oil analysis. It is a method of determining the concentration of various chemical elements in samples taken from oil and lubricating fluid-wetted components. Based on this concentration of chemical elements, the amount of wear metals in the specific sample can be determined. With knowledge of the metals adjacent to wearing surfaces, potential failures are predicted in the component system where the oil samples were taken.

Field units take oil samples from the components, (engine, transmission, gear boxes and hydraulic systems) and forward the samples to a laboratory. Here, an evaluator determines if the test results show evidence of potential failure. When the evaluator identifies an impending failure the suspect component is replaced and sent to a maintenance unit for teardown analysis. The results of the teardown are sent back to the field unit, the evaluator, and U.S. Army DARCOM Materiel Readiness Support Activity.

Objectives of AOAP are:

1 Enhance safety by improving the methodology and procedures of detecting impending equipment component failures, extend operational readiness of Army equipment through the efficient and effective use of oil analysis, and promote the coordination and cooperation of the user.

2 Reduce maintenance costs through preventive maintenance efforts prior to major repair as indicated by symptomatic techniques.

3 Integrate the oil analysis program into the maintenance engineering effort to develop techniques, methods and practices for improving and reducing maintenance costs.

3.7.6 On-Condition Maintenance (OCM) (Vehicle Overhaul Selection)

Purpose: Provide a technique for selection of Army equipment for depot maintenance (aircraft are presently under this program and the program is being tested on combat vehicles such as the M-60 tank) most in need of return to depot. This is an improvement over the previous operating hours or calendar time techniques.

The on-condition selection of equipment for overhaul falls within the RCM task umbrella because periodic inspections are performed to ascertain condition of the equipment. These periodic inspections can be considered within the RCM on-condition task classification.

The OCM concept uses the results of periodic evaluations. The Analytical Condition Evaluation (ACE) (also called Aircraft Condition Evaluation) of Army equipment determines its condition by inspection of key drivers. The drivers are significant indicators of an equipment's condition. Individually inspected items are numerically weighted relative to their importance. The numerical sum of the values is the basis of a Profile Index (PI) for each item. When the PI exceeds an established threshold for the equipment type, it is tagged as an overhaul candidate. This process results in identification of equipment most in need of early depot attention.

Other OCM program functions include:

1 Staffing and training of permanent teams to perform ACE

2 Development and monitoring of computer programs for determining equipment candidates for depot overhaul

3 Determination and recommendations concerning the PI threshold

4 Accumulation of statistics and analysis of failure occurrence frequencies.

3.7.7 Project Inspect (PI)

Purpose: Reduce field maintenance and increase operational readiness of Army aircraft.

Project Inspect can be considered a quasi-RCM program only because some elements found in RCM programs are input to a computer math model to be used in computing the inspection interval.

Project Inspect is the result of Army research into modern approaches to aircraft reliability and maintainability programs. Aircraft preventive maintenance inspection schedules are developed through computer modeling, based upon advanced component failure theory. Checklists for existing aircraft are provided to ensure maximize intervals between inspections, consistent with aircraft safety and overall cost effectiveness.

Inspections are both daily and phased. Daily and special inspections have not been considered for change to date. Phased inspections occur at regular intervals. A set of these inspections comprises a cycle.

Proper scheduling of individual component inspections, based upon failure and failure detection historical data, allows inspection intervals and cycle times to be increased during Phase I of Project Inspect inspection lists were developed for the UH-1 and CH-47.

helicopters. The lists were based on actual field maintenance data, experience, and safety criteria for the UH-1. From these inspections were optimized a 100-hour interval, 800-hour cycle. The net result was a significant reduction in scheduled maintenance manhours and a significant increase in time between major inspections.

Project Inspect uses a computer program identified as MAVIS (Model for Analysis of Vehicle Inspection System), which was designed to determine the inspection intervals for the systems and equipment used in manned aircraft. MAVIS is structured to provide a systematic method for evaluating the effectiveness of alternate inspection concepts. The parameters required to perform the calculations are extractable from existing inspection data. The model sequentially applies the basic analytical concept to the spectrum of components. Analysis of the MAVIS model is contained in Exhibit X.

Such factors as failure rates and failure modes (limited to three per item) are factored into the MAVIS model, along with data on the criticality of the failures. The output provides a characteristics profile of the inspection scheme for each item. This data provides the engineer with the means for determining the optimum inspection scheme for the aircraft under consideration.

As a result of Project Inspect, phase maintenance has been implemented in Army Aviation Maintenance.

3.7.8 Project LEAP (Logistical Efficiencies to Increase Army Power)

Purpose: To review organizational scheduled maintenance requirements and reduce and eliminate those that have marginal value.

Scheduled maintenance of equipment involves a wide range of maintenance actions, the primary purpose of which is to maintain operational reliability by finding potential failures and correcting the condition before the failure occurs.

Project LEAP is one of those programs that is closely allied with the RCM program, in that Project Leap was the forerunner of the PMCS Review.

Project LEAP required a review of the organizational scheduled maintenance requirements, found in the technical manuals, to identify candidate resource savings which could be realized through reducing or eliminating all organizational scheduled maintenance requirements that do not have a time-proven value in maintaining operational readiness.

Although Project LEAP was terminated in 1976 after being applied to twelve pilot items, reduction of PMCS for fielded systems was continued under RCM. Under Project LEAP, screening of the technical manuals was accomplished based on the judgment of the individual doing the screening. Decision logic has replaced judgment when RCM objectives were added to the screening process.

3.7.9 Equipment Serviceability Criteria (ESC) Elimination

Purpose: Elimination of the Equipment Serviceability Criteria Manual as a separate publication.

Since all ESC items result in an on-condition task requirement (repetitive inspections or tests to determine the condition of the system/-equipment) ESC tasks fall under the RCM task umbrella.

As the result of a FORSCOM study, which stressed the reliability and utility of information reported on equipment status, the decision was made to eliminate the Equipment Serviceability Criteria Manual. The items required to determine equipment status were incorporated into the PMCS tables of the operator's manual under the heading for readiness reporting. Only those items with a criteria for "Red" status are included in the PMCS tables. Determination of the not ready/available status now becomes a crew function.

3.7.10 Preventive Maintenance Checks and Services (PMCS) Review

Purpose: Reduce or eliminate those preventive maintenance checks and services which have a marginal value in maintaining maximum equipment efficiency or are ineffective in discovering defects or failures.

PMCS review is a continuation of the effort started under Project Leap. The difference between the two programs is that under Project Leap the screening was largely a matter of judgment, whereas under the present program the elimination of checks and services are the result of the application of decision logic in the screening process.

This requirement for use of decision logic qualifies PMCS review as an RCM task.

The PMCS review consists of identifying each PMCS numbered item and subjecting it to the questions of the review logic. The review logic questions aid in determining what scheduled maintenance is required. After it is determined that maintenance should be performed, the type of maintenance action (on-condition or hard time) and frequency of application (daily, weekly, monthly, and before, during, and after operations) are specified.

In determining what maintenance tasks apply for any particular situation, only those tasks necessary to prevent deterioration of the equipment and to detect possible or actual failures are considered for retention. Those reliability maintenance requirements which are unnecessary or only marginal in value will be eliminated from the PMCS tables.

3.7.11 DMWR Scrub

Purpose: Achieve compatibility with the RCM philosophy in the performance of depot maintenance through an in-depth review of the present content of the DMWRs.

The DMWR scrub uses decision logic for screening the content of the DMWR. Its ultimate purpose is to reduce the cost of depot overhaul. This requirement to use decision logic qualifies the DMWR scrub as an RCM task.

Application of the decision logic to any depot overhaul task results in the selection of one of three maintenance task categories: Condition Monitoring, Hard time Limit, or On-Condition. Elimination or reduction of the depot maintenance tasks at the same time maintenance costs are being reduced should not prevent the depot from maintaining a quality product output from its overhaul program.

3.7.12 RISE

Purpose: Improvement of RAM performance and reduction of life-cycle maintenance cost through equipment redesign.

RISE is one of a group of programs allied with RCM. It requires that RCM principles be incorporated into the engineering, cost, and decision risk analysis parts of the RISE program.

This program is conducted in four phases:

Phase 1. Assessment of those problems which contribute to degradation of RAM performance and contribute to excessive maintenance support costs.

Phase 2. Performance of engineering and cost analyses to develop feasible alternates for correcting the problem.

Phase 3. Implementation of those corrective actions where the most potential exists for maximum return on investment at an acceptable risk.

Phase 4. Verification of achieved improvement in RAM performance and the impact of reducing life-cycle maintenance.

3.8 Analysis of ILS/LSA/RCM Interrelationships

3.8.1 Background

Logistic support is a prime consideration in the early stages of system development. Starting with the conceptual phase, the logistic support analysis (LSA) is performed to evaluate operational and design characteristics to substantiate maintenance support decisions. Through the accomplishment of LSA tasks, ILS requirements are identified, defined, and processed. Application of RCM, because of its potential impact on maintenance program development, will be made through the LSA. Toward that end, MRSA has developed Appendix C to AMCP 750-16 "DARCOM Guide to LSA" entitled "Analysis Guidelines for Determination of the Maintenance Plan Using the Principles of RCM."

3.8.2 Assessment

The detailed analysis performed on Appendix C is published in the Martin Marietta Corporation document OA 7815-4, which is included as a portion of Exhibit XI of this report. As a part of the evaluation, recommendations were included for specific changes to the RCM decision logic and amplification of the areas on cost considerations, sample logic applications, and determination of maintenance task intervals.

As an overall assessment, Appendix C meets the requirement for establishing guidelines necessary to apply RCM principles to maintenance program development for new systems or equipment. Through implementation of its guidelines, the application of RCM to the LSA will not disrupt the integrity of the present Army ILS structure.

3.8.3 Discussion

As indicated by its title, Appendix C provides guidelines for including RCM principles in the development of maintenance programs for systems and equipment. Implementation of these guidelines is intended to facilitate integration of RCM to the LSA, from which the maintenance plan evolves. The contents of Appendix C was evaluated to determine their effectiveness in making application of RCM to the LSA process.

As a prerequisite to the evaluation, an overview of a viable RCM program was defined. This was done by identifying the essential tasks required for effective implementation of RCM:

1 Development of required input data

2 Development of RCM decision logic

3 Application of input data to the logic

4 Recording of logic decisions

5 Implementation of RCM decisions.

Interface of the basic LSA characteristics, and those introduced through Appendix C, which satisfy these RCM program requirements are shown in Figure 1.

Required input data, for application to RCM decision logic, include the identification of maintenance significant items (MSIs), a failure mode effects and criticality analysis (FMECA) on the MSIs, and reliability/maintainability (R/M) data. This information is inherent to the LSA and is recorded on the B sheet, entitled "Item Reliability and Maintainability Characteristics."

The RCM decision logic is developed as part of Appendix C. It is designed to place emphasis on components that are critical to safety or reliability. It also highlights potentially effective scheduled maintenance tasks for those component items. The basic criteria included in the logic are: 1) scheduling of maintenance tasks on critical items when

RCM PROGRAM REQUIREMENTS	LSA INTERFACE
• INPUT DATA	B SHEET
• RCM DECISION LOGIC	PART OF APPENDIX C
• APPLICATION OF INPUT DATA TO LOGIC	PART OF APPENDIX C
• RECORDING LOGIC DECISIONS	MODIFIED B SHEET (APPENDIX C)
• IMPLEMENT RCM DECISIONS	CD SHEETS

Figure 1. RCM/LSA Interface

inherent safety and reliability levels can be preserved or when support costs can be reduced, and 2) scheduling of maintenance tasks on non-critical items only when support costs can be reduced.

Application of the B sheet data to the logic is described in detail in Appendix C. The inclusion of several sample cases facilitates the understanding and utilization of the logic.

Recording of the logic decisions is accomplished on the B sheet, as modified by Appendix C. Through addition of the RCM analysis section, the B sheet facilitates the application of RCM to the LSA process by providing for:

1 The recording of answers to applicable logic questions for failure modes, identified in the FMECA, of MSIs.

2 The recording of the disposition of each failure mode processed through the logic. This is the initial indication, within the LSA, that a potential RCM scheduled maintenance task may be required in the maintenance program.

3 The documenting of the unique task code for each RCM task identified.

Implementation of the RCM decisions is accomplished through the completion of the C and D sheets ("Task Analysis Summary" and "Maintenance and Operator Task Analysis") for all the identified scheduled maintenance tasks. Identification of a task is retained through its unique task code. The C sheet shows task and personnel requirement summaries. The D sheet reflects sequential task steps, descriptive information for publications use, information for training requirement determination, and support equipment and repair parts requirements.

A graphic display of the RCM/LSA integration process is shown in Figure 2. The inherent LSA characteristics, including those added by Appendix C, and the RCM integration task flow depicted indicate a high degree of compatibility between the LSA and RCM. Since the LSA is used to satisfy ILS requirements, there is an intimate ILS/LSA/RCM interrelationship established through the application of the Appendix C guidelines.

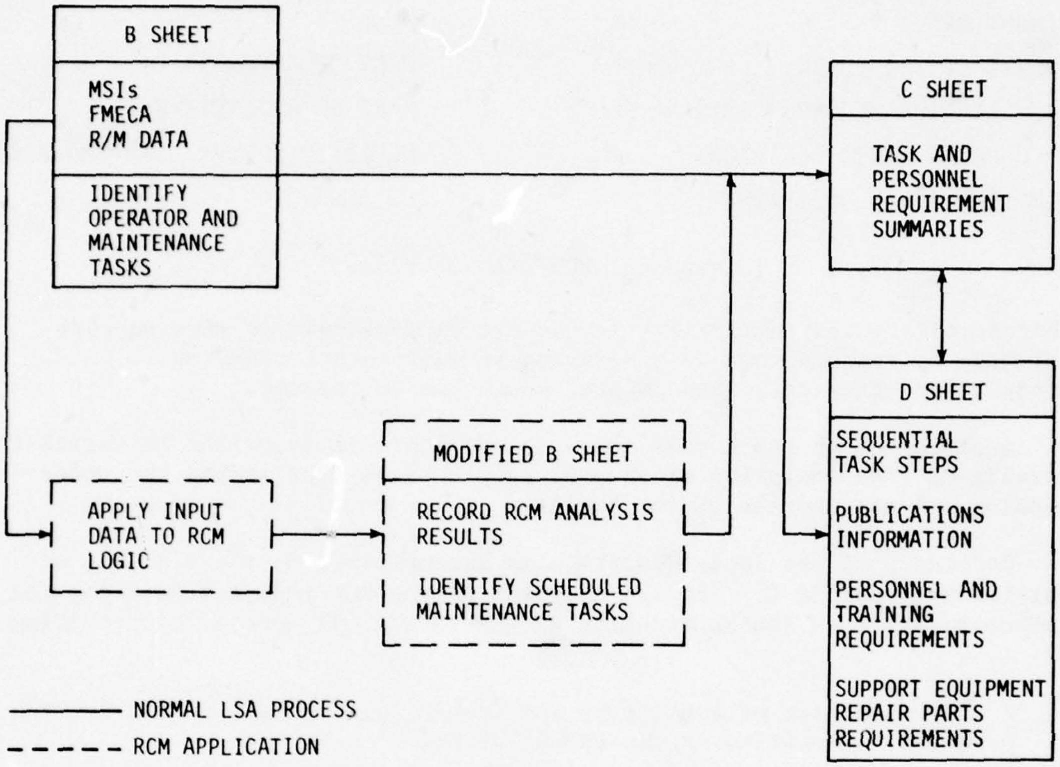

Figure 2. RCM/LSA Integration

3.9 Evaluation of RCM on Fielded Systems

3.9.1 Objective and Scope

The Martin Marietta evaluation team reviewed the entire history and formulation concepts of the air carriers MSG-2 program in order to develop an appropriate basis for uniform evaluation concepts for use in Army assessment of RCM implementation. DoD's intentions to retain reliability while reducing excessive maintenance through RCM, and the subsequent Army adaptation of MSG-2 were examined. This was done to determine underlying and obvious aims and objectives. In order to both extend and intensify our depth of knowledge, additional study was made of all other programs, either related to RCM by common element or directly modified therefrom.

This historical documentation investigation brought out the fact that no single, definitive, and comprehensive plan existed to be used satisfactorily as a measuring standard for assessment of Army RCM. Numerous letters and directives had been issued identifying the reasons for activating the program and its basic precepts, but a clear, uncompromising definition and positive procedural details were not available. To fill this significant void, OA 7815-3 (Appendix A - Martin Marietta plan for the Development of a Reliability Centered Maintenance Program for Existing Systems/Equipment) was published in December, 1977.

A list of five candidate systems was established at the December 1977 SAG meeting. One from each readiness command was selected for assessment of RCM implementation. They are listed below: (Exhibits I through V provide details of assessment of each product).

1 UH-1H Utility Helicopter - TSARCOM

2 TOW Heavy Antitank/Assault Weapon System - MIRCOM

3 M-113 Armored Personnel Carrier - TARCOM

4 AN/VRC-12 Radio Set - CERCOM

5 M-110 Self-Propelled Howitzer - ARRCOM

SAG selected these particular systems because the equipment population of each was relatively high, and because their diversity in mission, operation, and maintenance requirements would enable the assessment survey to provide a broad picture of RCM activity. This assessment was necessarily oriented to activities of these five readiness commands to determine the current status of accomplishment on the selected fielded systems. It followed that evaluation of the adequacy of programs on other systems might reveal additional information applicable to RCM objectives. This slightly expanded investigation yielded valid survey benefits. It was found, for example, that certain of the selected candidate systems had not been subjected to RCM revisions yet, whereas greater progress had been made on similar systems. The following evaluation of RCM implementation on fielded systems therefore considers readiness command plans and activities on a slightly larger scope than the five selected systems, in order to provide to the Army improved cost effectiveness under contract DAAG 39-77-C0169.

3.9.2 RCM Application

Initial investigation consisted of telephone conversations with the RCM action officers of each readiness command. These were to determine current status of RCM planning activities and to request copies of the directives and guidelines received. The calls were made to determine whether intended RCM goals of these commands were the same as those apparently intended by the Army and DoD. Verbal interchanges and reviews of these working documents gave the first indication that interpretations of

the RCM program were not identical among the readiness commands: that none of these conformed completely to the program intended for implementation Army-wide. In most cases, early inquiries at the working level revealed an apparent lack of requirement for usage of failure mode and effects analysis data in the readiness commands. That is, engineering analysis of field data was being bypassed in favor of engineering judgement, based on personal field maintenance experience. DARCOM, in instructions to commodity commands, failed to include engineering analysis (FMECA/FMEA) as a requirement for an effective RCM program. During subsequent on-site visits it was found that one of the underlying causes of this deviation was the unavailability of field data at the assembly or component level.

The on-site reviews were conducted over a two month period between the end of February and the first of May at the headquarters of the readiness commands. These consisted of numerous interviews of personnel involved with RCM, from program management and planning levels on down. Internal documents, forms, planning layouts, and work sheets were examined in depth to obtain a thorough understanding of the RCM actions being accomplished, and the underlying reasons and basic intentions of the methodology in use.

The first step in formalized RCM processing, based on MSG-2 principles, is determination of equipment items which impact system maintenance requirements. Generally speaking, maintenance significant items (MSI) being used for RCM processing by the readiness commands are limited to those items listed for maintenance attention in the current preventive maintenance checks and services (PMCS) sections of operators and organization maintenance manuals. These type items probably constitute the majority of MSIs in each system. Nevertheless, other assemblies or components which have contributed to mishaps, mission failure, aborts, delays, unsatisfactory conditions, or system degradation should have been included.

MAVIS, which was developed specifically to process field data for Army aviation, uses a list identified as Master Configuration File (MCF) items for a purpose similar to MSI. However, this has been applied to date only to UH-1H and CH-47 helicopters. Lack of a comprehensive MSI list is known to have caused omission errors in at least one readiness command.

Recent documents issued by the three military services and DoD indicate that the two most significant factors that segregate RCM from other maintenance planning programs are 1) engineering analysis of field usage and failure data records (FMEA developed by the analyst, or FMECA prepared by the equipment contractor) and 2) processing of MSIs through formalized decision logic questions. The FMEA (or FMECA) is designed to provide quantified data, establishing a provable base of actual field problems to estimate reliance upon personal experience or the intuitive judgement common to other maintenance planning programs. Use of the decision logic questions ensures that all the maintenance planning factors are considered by the RCM analyst, and that various analysts will consider these same factors in a uniform manner.

FMEA, as a disciplined review of hard facts pertaining to operating equipment failures, was seldom used in the Army RCM programming investigated. In development of phased maintenance for UH-1 aircraft, a maximum of three failure modes and resulting effects for each MCF identified are inserted into the MAVIS model. For some items, this could be sufficient, although for a large assembly such as a helicopter jet engine (one MCF item) three is obviously an insufficient number to cover the anticipated failure modes. In order to be an effective tool, the FMEA should include most possible failure modes applicable to an assembly or component, and particularly those included in equipment failure history. Development of an appropriate FMEA requires full understanding of the hardware and precise descriptions of the types of failures, plus effects and consequences and summarization of component and assembly failures for high level assemblies. Inability of the readiness commands to achieve this depth of analysis in RCM processing indicates that maintenance manuals revised through current RCM efforts may contain some unnecessary PMCS, and fail to include others of potential benefit.

Fault Detection and Locations Analysis (FDLA) is a useful RCM device applicable to certain types of MSI. Determining the source of many types of failures in equipment (such as hydraulic fluid leaks, broken antenna, discharged batteries, out-of-balance helicopter rotor blades, and distorted optical lenses) constitutes no problem in fault detection or location problems for PMCS development. However, equipment deficiencies such as loss of an incoming RF signal, or incomplete firing of an internal combustion engine, are failures that can result from a variety of basic causes. In these cases, determination of appropriate maintenance action on complex assemblies cannot be made from FMEA data. It is then necessary to develop a FDLA, or else extend the FMEA to the lowest assembly or component level, to obtain the data needed for selection or the best method of reliability retention at lowest cost. The basic need for fault detection and location information is evidenced by the increased incorporation of built-in-test-equipment (BITE) in the more advanced, sophisticated military equipment now under development. BITE is being improved and expanded for the express purpose of reducing time required for fault correction or prevention.

Validity of FDLA preparation in RCM programming has not been recognized by the Army. Directives, instructions and guidance to readiness commands do not mention this type of analysis, although some guidelines suggest carrying FMEA down to the component levels. It was not surprising, therefore to find such analyses missing in Army RCM implementation.

MSG-2, the forerunner of RCM strategy was developed by the Air Transport Association. It instigated decision logic as the primary processing tool for determining minimum maintenance requirements consistent with retention of designed equipment reliability. The logic diagram developed in MSG-2 was heavily theoretical in nature, verbose in construction and included parallel decision paths, all of which caused it to be difficult to follow and confusing to use. Simplification of this diagram was indicated prior to issuance of usage requirements for RCM purposes. A number of revisions were attempted by DARCOM to develop an easily useable diagram, but

they resulted in misunderstandings of benefit potential and, in some commands, resistance to acceptance. One of the major difficulties in this area is that no single logic diagram has been devised which is ideally suited for the varied systems encompassed in deployed Army equipment. Since guidance in logic diagram modification was incomplete, RCM action personnel in three readiness commands could not make use of any formalized logic. One command was using the proposed logic diagram in AMCP 750-XX, "Guide to the Application of Reliability Centered Maintenance to Preventive Maintenance Checks and Services for Non-aeronautical Equipment (Draft)," issued in January, 1978. One other command prepared an RCM implementation plan which included a modified logic diagram for fielded systems PMCS review. But the capability of their logic to contribute to successful processing was degraded, due to insufficient engineering analysis. Development of phased maintenance for aircraft included certain manual inputs to the MAVIS model which have some relationship to specific questions in RCM logic. Examples of these are criticality of an MSI failure, repair manhours for inspection type items and identification of high failure rate items. The basic purpose of MAVIS, though, is to help engineering personnel optimize inspection intervals, rather than determine the best type of maintenance for each item. Army-wide, decision logic has not been used in either the extent or manner intended by the directives.

An inherent part of comprehensive maintenance planning, although not specifically identified as an RCM element by DARCOM guidance, is the integration of other maintenance programs and directives into PMCS revision. Special attention must be given to such general requirements as corrosion control, personnel safety, and chemical-biological-radiological provisions. In addition, direct system evaluations of failure analysis to determine the underlying causes of individual item failures must be conducted. With certain exceptions, these considerations have been included in maintenance programming revised since RCM advent. In one instance, this interfacing was apparently accomplished, but not indicated in documents. In two others, applications of maintenance evaluation of reported field problems (failure analysis) which could yield benefits were not completed. These latter cases (described thoroughly in Exhibits II and V) are examples of data on hand in readiness command records that are ideally suited for incorporation in RCM engineering analysis.

Following the draft of PMCS requirements through RCM strategy, the next logical step is to draw a comparison between the proposed revisions and the previous maintenance requirements to estimate the benefits anticipated. This comparative analysis most often has consisted of two main considerations, the number of tasks per plan, and the manhours required to accomplish the tasks included in each. Other factors that have a bearing on expected benefits which could be compared include 1) mean time between maintenance actions, 2) the number of personnel and personnel skill levels required, 3) test equipment and facilities needed, 4) repair parts indicated, and 5) transportation and handling costs.

The Martin Marietta survey revealed that all five readiness commands have compared number of tasks in the old plan to the proposed revision. In some cases manhour requirements were compared. Manhour requirement

comparisons accomplished by three commands provide better estimations than simple task counts. Generally, tasks were reduced in the draft revisions, but it was noted that some of the new task requirements encompassed an equal or larger scope of maintenance work than several old tasks for the same MSI inspection. Such a situation would nullify the validity of estimating savings based on task count alone. Shop simulation of tasks to determine time needed for each task is used in at least one command RCM effort. This is not equal to field experience, but it is considered superior to reliance on personal intuitive judgement in establishing manhours required. To date, the other comparative factors mentioned in the previous paragraph have not been applied in potential benefit analysis by the readiness commands.

No evidence was found to indicate that any RCM program in the readiness commands had progressed sufficiently in the development of procedures for audit trail tracking of field RCM. In most cases, the RCM activity appeared to be viewed as a one-time effort on a fielded system. Anticipated obsolescence of those systems already deployed undoubtedly promotes this apparent attitude. Similarly, sustaining engineering plans and activities were found to be non-existent in the areas included in the scope of this assessment.

3.9.3 RCM-Related Programs

3.9.3.1 Several programs initiated prior to adoption of RCM as a maintenance planning requirement are considered by the Army RCM programs. They consist of the following:

1 Army Oil Analysis Program (AOAP)

2 On-Condition Maintenance (OCM)

3 Project LEAP

4 PMCS Review

5 Three-Level Maintenance

6 Phased Maintenance (Developed via Project Inspect)

7 Logistic Support Analysis (LSA) (Succession to Maintenance Engineering Analysis)

The relationship of each of these programs to RCM is established through published statements which detail the intent and objective of each program. Therefore, the previous programs are evaluated here as each relates to the two interactive elements of the RCM main objective: 1) Retention of inherent equipment reliability throughout systems life cycle, and 2) reduction of maintenance cost to the lowest level consistent with retention of reliability.

3.9.3.2 Army Oil Analysis Program (AOAP)

The basic purpose of oil analysis is to provide an indication of the internal condition of engines, transmissions, gear boxes and similar assemblies containing oil or hydraulic fluid. Oil samples are taken on a periodic basis (usage hours or mileage covered) and forwarded to a laboratory where spectrometric analysis of the samples are made. The concentration of contaminates such as metal wear, water, rust particles, chemicals, and fuel serve to speed the deterioration of the assembly and identify failure of bearings, shafts, gears and other assembly components.

The scheduled requirement for drawing the oil sample is an On-Condition inspection or test within the terminology of RCM. However, since the purpose of making the analysis is to locate degraded parts and accomplish repairs prior to actual failure (equivalent to the purpose of RCM condition monitoring), this program relates to both elements of the RCM objective.

The adequacy of AOAP in averting costly failures and in assuring operating personnel that the oil-analyzed assembly is serviceable has been accepted and recognized Army-wide for a considerable time. Expansion of the program to many types of equipment not currently included in AOAP is being implemented on some systems, and is under study for others.

3.9.3.3 On-Condition Maintenance (OCM)

This program, not to be confused with On-Condition service, test or inspection in PMCS, has been initiated to ensure that every piece of equipment selected for depot overhaul has an essential requisite for overhaul. Before the Army's OCM policy, equipment overhaul candidates were selected on a specified limit of mileage or usage hours since new unit acquisition or last overhaul. This hard time unit resulted in overhauls for some units which were still in serviceable condition. Concurrently, many prematurely deteriorated units which had not been used to the established hardtime limits would be left in deployed status, even though some of these might be unserviceable.

Action taken to eliminate non-productive overhaul and also increase the average serviceability for deployed equipment consisted of establishing the OCM inspection plan as a replacement for the hard time limit as the preferred overhaul selection method. The OCM plan includes establishing specific criteria to be considered in periodic inspections, weighted and computer-processed to create a digital profile index (PI) for each unit. Profile indexes for all equipment of a like nature are grouped for identification of those exceeding an established threshold for overhaul eligibility, and units having the highest PI become prime candidates for near-term overhaul.

A direct tie in with RCM objective is substantiated because OCM actually helps achieve greater use of funds budgeted for depot overhaul, and gives increased availability of deployed equipment. Aviation savings, based on fewer aircraft units overhauled in 1975 and 1976, have been estimated at \$47 million annually, although the OCM program is not the sole contributor to this. Reduced flying activity during the same period is

responsible for an undetermined percentage of such savings. Dollar savings have not been made available to date for non-aeronautical equipment overhauls that have been reduced or eliminated due to the OCM program. However, comparison of the number of units overhauled indicate that considerable reduction should be realized after OCM is fully implemented.

3.9.3.4 Project LEAP (Logistical Efficiencies to Increase Army Power)

This project was established in 1975 as a companion effort to Project 16-78, established in 1974 to increase Army combat capability to 16 active Army Divisions through savings in men, money and material by end of FY 78. Project LEAP was initiated as a test program to reduce or eliminate those organizational scheduled maintenance requirements having marginal value. Twelve pilot end items were selected for special review of PMCS requirements to determine what savings might be accomplished. The Final Report on Project LEAP, Issue 127, dated 1 January 1977, showed a reduction of maintenance manhour requirements that ranged from 1 percent (for radio set, AN/PRC-77) to 80 percent (for Continuous Radar, ICWAR). However, it was noted that actual reduction of personnel as a result of manpower savings could not be accomplished since personnel are essential regardless of maintenance simplification. Also, military occupational specialty (MOS) ratings could not be changed even though some tasks were reduced or eliminated. The Department of the Army in October, 1976 agreed with LEAP Final Report recommendation that separate manuals for Equipment Service Criteria (ESC) should be discontinued and ESC "Red Items" be incorporated into operator and organizational maintenance manuals during the implementation of RCM on fielded systems.

Project LEAP, Issue 127, proved the feasibility of reducing PMCS requirements for 12 pilot end items, and indicated that its application to Army equipment should be limited to high density, frequently used items. As a forerunner of RCM, LEAP served a useful purpose by showing that PMCS on Army systems could be reduced without impacting inherent reliability. Engineering analysis and decision logic were not identified as specific integral elements in LEAP as they are in RCM.

3.9.3.5 Preventive Maintenance Checks and Services (PMCS) Review

This program, an offshoot of Project LEAP, was initiated in June, 1976. It was designed to extend the review of PMCS for 12 pilot end items to change maintenance requirements for the remaining end items covered by ESC manuals. Priority of application was established for 57 maintenance significant items. Completion of printed changes for the 57 items was scheduled for 1 January 1977. The PMCS review period coincided with initiation of RCM, so it is reasonable to consider the PMCS Review as an "interim" program. Its basic aim, however, addressed only the revision of maintenance services to reduce the workload and to eliminate the ESC manual as a separate publication. RCM is much broader in scope, and considers the overall maintenance operation required to retain inherent equipment reliability. Due to the concurrent time periods and some similarity in purpose between PMCS Review and RCM, a confusion of the two programs apparently resulted in RCM being considered identical with PMCS Review by some readiness command personnel.

3.9.3.6 Three Level Maintenance

The fundamental purpose of this plan was to reorganize aviation maintenance to improve support activities for Army aircraft and thereby reduce equipment downtime for maintenance and increased operational readiness. Elimination of the Direct Service Unit permitted reassignment of half of its capability to the organizational level, renamed Aviation Unit Maintenance (AVUM) and the other half to Aviation Intermediate Maintenance (AVIM), previously known as General Support (GS). Some cost savings have resulted from better utilization of equipment, facilities and personnel skill levels although the primary aim was to increase aircraft availability. Increased availability implies restoration of inherent reliability which relates to one element of the RCM objective. Maintenance at three levels should entail lower budget requirements than the Army's traditional four level maintenance structure. Final determination of this relationship can be determined when figures are published showing the cost savings and operational readiness improvement achieved by three level maintenance.

3.9.3.7 Phased Maintenance (Developed from Project Inspect)

Project Inspect was a test program conducted on 120 UH-1 aircraft starting in 1971 to determine the effect of simplified maintenance procedures on aircraft availability, maintenance manhours and cost per flying hour. The first phase of the test showed a 73 percent reduction in maintenance manhours per flying hour, a 13 percent reduction in maintenance cost per flying hour and a 40 percent reduction in parts priced in excess of $200 each, whereas operational readiness was increased by 3 percent. Obviously, these achievements are in direct correlation with RCM's primary objective. Due to the success of the first test phase, phases II and III are in progress and the reduced maintenance program title Phased Maintenance has been implemented for Army aircraft worldwide. The main element of this program is that an entire aircraft is inspected over an 800 flying hour cycle, with various portions inspected each 100 hours. Under the previous program, the entire aircraft was subjected to complete inspections every 100 hours. Changes have also been made to the intermediate (25 hour) inspections, and additional changes are anticipated when daily and special inspections are reviewed through MAVIS model exercising.

TSARCOM's position that phased maintenance constitutes conformance to RCM requirements is partially supported because up to three failure modes for each assembly/component are considered by MAVIS modeling and because safety criticality and repair manhours are inputs to the program. Its basic purpose fits the general mold of RCM objectives. However, extension of engineering analysis (FMEA/FMECA) in greater depth, and application of formal decision logic to determine the optimum maintenance activity for every failure might result in even greater reduction of maintenance tasks than has been accomplished to date. Feasible application of a limited number of condition monitoring tasks might be uncovered to further reduce the scheduled maintenance currently required in UH-1. RCM also would appear to be less costly than expansion of Project Inspect testing to implement on other Army aircraft than UH-1 and CH-47.

3.9.3.8 Logistics Support Analysis (LSA) (Successor to Maintenance Engineering Analysis)

This program, LSA, is the heart of the Army's Integrated Logistics Systems (ILS), implemented after many years of study and promotion. As such, LSA considers a far broader scope of activities than encompassed by RCM. LSA primarily covers operational and maintenance requirements, including reliability and maintainability characteristics of systems and equipment. The LSA subsequently identifies total operation and support (O&S) requirements that are considered in final determination of the overall maintenance plan, including personnel numbers and skills, repair parts and materials, test equipment, training facilities, packaging and transportation. Because of Appendix C to AMCP 750-16, which was incorporated into the basic LSA document officially in February, 1978, RCM should become an integral part of LSA on those systems and equipment contracted for development in the future. Fielded systems will require separate RCM processing, as will those development systems contracted prior to 1978. The complete evaluation of the LSA/RCM relationship is discussed in detail in the preceding subsection of Section 3 (Analysis of ILS/LSA/RCM) and LSA is mentioned as the vehicle for RCM in the subsection evaluating RCM on developmental systems.

3.9.4 Analysis of RCM Cost Benefits

Considerable effort was expended by Martin Marietta assessment investigators to ascertain the existence of a method for determining an accurate measurement of benefits accruing from implementation of RCM on military systems. Surveys were conducted of attempts by the U.S. Navy, Air Force, commercial air carriers, and other organizations to determine exact values of similar maintenance revision programs. Specifically, a method of measuring the cost impact of changes to a maintenance program brought about by the application of RCM was required. Apparently, a comprehensive cost analysis method has not been developed to date.

The basic difficulty in measuring benefits is assignment of fixed values to intangible factors which are affected by modifications to weapon systems maintenance, for example, determining the amount of savings to be realized if an accident is averted through prevention of equipment failure, or calculating the dollar loss or expense of a multi-unit mission that must be aborted due to failure of a key piece of equipment. This type of information cannot be quantified accurately enough to develop a true cost benefit analysis of RCM application.

Narrative evaluation of RCM benefits has been included in preceding paragraphs of Section 3.0 and also in Exhibits I through V pertaining to the readiness command activities. The paragraphs which follow contain information on estimated savings and cost benefits noted by the other services, and outlines the scheme developed by Martin Marietta to measure tangible element benefits of RCM versus other maintenance planning programs.

The January 31, 1977, issue of Aviation Week and Space Technology reported that the Navy had experienced sizeable dollar savings through the implementation of RCM on its P-3 aircraft. These savings were identified as a 21 percent reduction in both organizational and intermediate level maintenance, and a 15 percent reduction in depot level maintenance over a three year period. It was estimated that the Navy saved $20.7 million in costs in 1976 through an RCM program that was fully implemented on the P-3 and partially on S-3 aircraft and J-52, J-60, and J-79 engines. Because of this, a cost avoidance of $28 million was included in the Navy's 1979 budget plan. These cost avoidances resulted from the deletion of unnecessary and ineffective maintenance tasks and from increasing depot maintenance from a three year to a five year interval.

Strategic Air Command maintenance personnel positions were reduced by 800 because of projected RCM benefits on the B-52 and KC 135. The Manpower Reserve Affair & Logistics staff objected to these cuts because they felt there was insufficient time to determine the data base for making reliable estimates of the savings. As a result, it was necessary for the Air Force to transfer funds from other repair areas to cover the actual maintenance cost for aircraft and engines. In the FY 79 budgeting, OSD/OMB reduced the Air Force's depot maintenance by $3.2 million for aircraft and $54 million for engines, based on RCM "savings".

The Navy was contacted to determine whether there had been a cost benefit methodology used to determine the figures published in a P-3 maintenance program savings, resulting from the implementation or RCM. It was learned the Navy had not developed the means of comparing the total costs derived from employing one maintenance concept against RCM. The "savings" published are cost reductions resulting from deleting tasks or increasing maintenance intervals. For those tasks that remain in the maintenance program but changed in scope, no cost comparison figures were available.

The Air Force was contacted to determine if they had a methodology for comparing the cost benefits between two maintenance programs. Using the C-141 as a test case study, the Air Force developed the RCM Benefit Assessment Program Plan. The basic idea in conducting a test case study is to investigate benefits to be gained as the result of implementing an RCM based program or scheduled inspections. After investigation, the Air Force will be in a better position to suggest modes of analysis to complete similar assessments on other weapon systems on which RCM has been implemented.

The assessment plan was developed in response to a report from the Air Force Audit Agency which requested that the Air Force Logistic Management Center (AFLMC) requires program managers to accumulate data and assess the impact of RCM. In establishing the requirement for developing the C-141 assessment plan, AFLMC decreed that RCM is not to be used as a manpower determination process. Therefore, at the direction of the Chief of Staff USAF Systems and Logistics (Office for Maintenance Engineering and Supply), the C-141 study does not address maintenance manpower.

The C-141 assessment assumes stable periods of maintenance during which one maintenance program can be compared to another. The theory is that a learning period, wherein the maintenance program characteristics fluctuate, is followed by a period wherein the maintenance characteristics are stable. The Air Force proposes to compare data from these stable periods before RCM with the stable period that materializes after RCM implementation.

The C-141 program uses 19 indicators, such as aircraft availability, abort rate, inflight failures, operational readiness, number of maintenance actions, etc. to assess RCM benefits. Most of the indicators have an intangible value that cannot be measured in dollars. Therefore, there is little possibility of determining the dollar value between the pre-RCM and post-RCM maintenance programs.

This Air Force program is not adequate to fulfill Army goals. It does not take manpower into consideration at all, nor does it measure, or state how to measure, tangible or intangible variables.

In surveying the airlines, Eastern replied that it simply did not know a way to quantify cost benefits resulting from the incorporation of maintenance changes. Mr. F. Stanley Nowlan and Howard Heap summarized the airline position on evaluation of maintenance cost when, in the manuscript for the DoD "cookbook" of RCM, they stated:

> "Reliability-centered maintenance resulted in a marked reduction in the cost of scheduled maintenance (chiefly because the RCM analysis identified and deleted tasks that were unnecessary or ineffective); and this was done with no adverse effect on mechanical reliability. It is somewhat difficult to identify the actual cost reductions, since the airlines required between ten and fifteen years to accomplish the transition from traditional scheduled maintenance philosophy to the RCM philosophy. Maintenance programs changed continually during these years, and each change involved cost-effectiveness. Thus there is no marked discontinuity in existing maintenance-cost records to mark the advent of the new philosophy."

After contacting the Navy, Air Force, and airlines, it was concluded that there was presently no acceptable method of measuring cost effectiveness of maintenance program changes. What had been developed was not sufficient. Estimates of the total economic benefits cannot be accurately made until an appropriate methodology is designed.

Martin Marietta has developed a scheme to measure the elements involved in the cost of the pre-RCM and RCM programs. This scheme was needed in order to determine specific delta costs between various tangible elements of the maintenance programs.

When making a comparison between pre-RCM and RCM programs, it is not difficult to compare such items as clock time, maintenance manhours, labor costs, material costs, and test equipment costs. These are all tangible

variables which can be measured directly. These factors can be combined into one equation to determine the cost of a preventive maintenance program:

$$\text{RCM program cost} = \text{PM cost} \times \text{no. units} \times \text{no. yrs}$$

$$\text{PM costs} = \sum_{i=n} \text{cost of PM tasks} \times \text{no. units} \times \text{no. yrs.}$$

where

$$\text{Cost of PM task} = (\text{T/task} \times \text{P/task} \times \text{GD}) + \text{MAT} \times \text{no. tasks.}$$

PM = Preventive maintenance
T = Time
P = Number of personnel
GD = Military grade converted to standard rate per hour, computed from Army Cost Planning Handbook
MAT = Material items costs
TE = Test equipment costs
no. units = Units at any level (company, battalion, total inventory, etc.)
no. tasks = Number times task performed during a period of one year.

Using specific pre-RCM and post-RCM plans, many specific costs and other data can be determined. The cost of a specific task in two programs can be calculated and compared. In most cases, the cost of a specific task is the same in a pre-RCM and RCM plan. However, a RCM program cost savings occurs when, in the RCM program, 1) the actual number of tasks needed to be performed decreases and 2) the scope of the task decreases, 3) there are less items which need to be removed for rework, and 4) the time between scheduled tasks increases.

Data easily determined by using direct means are maintenance manhours, material costs, and test equipment utilization costs. Maintenance manhours can be calculated by multiplying the maintenance hours per task by the number of personnel who work on the task. The sum of the cost of each material item makes up the material costs. The impact on cost of test equipment is calculated by adding or subtracting the value of test equipment cost that may be required or deleted as the result of RCM. The dollar value of the delta cost of a pre-RCM and RCM program is determined by subtracting the total cost of the pre-RCM maintenance program from the RCM maintenance program total cost.

It must be cautioned that RCM is not a manpower determination process. Maintenance manhours cannot be equated with manpower requirements. With RCM, it is predicted that less manhours will be spent on maintenance work. This would seem to allow less men to perform maintenance tasks. However, there are other contributing factors. The number of men which can be removed from performing maintenance is limited by the fact that much preventive maintenance is performed by operators with some assistance by organizational maintenance personnel. A certain number of operators are still needed to perform their tasks of operating vehicles. Maintenance personnel are assigned by MOS. These specialities may be required to maintain other equipment. Therefore, the total manpower requirements for TO&E operator or

maintenance personnel may not be reduced as a result of implementation of RCM. Likewise, the reduction of depot maintenance requirements due to the implementation of RCM may have little or no impact on the depot manning tables due to the number of outside influences. Before a reduction in the work force is made, consideration is given to such items as economic impact on the local communities, whether the surrounding area can absorb the skill of those to be discharged from the depot, what the chances are that the discharged workers will remain in the vicinity to create a labor pool to be drawn from when needed, and what could be the political ramifications of a layoff.

Although RCM cannot be used to directly establish manpower level it does affect manpower utilization in the following ways:

Variable	Hypothesis
1 Time spent on PM	Will decrease
2 Time available for prime duty	Will increase
3 Time available for training in combat skills	Will increase
4 Skill level for PM tasks	May decrease
5 Time spent on maintenance training of personnel	May decrease

Besides the cost impact of RCM on directly measured items, RCM also has an impact on such intangible items as availability, aborts, mission performance, etc. These costs cannot be determined directly and depend on how preventive maintenance affects reliability rate in the existing system. One of two conditions will exist in the system, defining the effect of preventive maintenance on the reliability rate: the present system meets the inherent reliability rate, or the system is below its inherent reliability and RCM program restores the inherent reliability.

If the present system meets the inherent reliability rate, the difference between preventive maintenance costs in two different maintenance programs can be measured by using the preventive maintenance cost equation and simply subtracting one result from the other. The RCM preventive maintenance program would have no effect on reliability rate.

If the system is below its inherent reliability, the RCM preventive maintenance program improves the system. In this case, certain changes will occur:

Variable	Hypothesis
1 Equipment availability	Will increase
2 Reliability	Will increase
3 Aborts	Will decrease

4	Mission failures	Will decrease
5	Accidents Maintenance Material	Will decrease
6	Readiness	Will increase
7	Number of maintenance actions	Scheduled: change* Unscheduled: remain same
8	Requests for GS and DS assistance	Will change*
9	Remove and replace actions	Will change*
10	Inspection frequency	Will change*

*Numbers 7 - 10 are all related. An increase in number 7 will bring about an increase in the others. A decrease in number 7 will cause a decrease in the other three.

It should be noted that there are certain initial costs involved with implementation of RCM. These are the costs of three phases: 1) analysis phase for developing maintenance plans, 2) implementation of developed plans, 3) setting up sustaining engineering efforts that would become a part of the regular support programs.

The tangible changes can easily be determined, but the intangible items cannot be determined in specific dollar values. Therefore, this does not offer to the military a way to calculate the total cost benefits of using RCM.

3.10 Evaluation of RCM Impact on Developmental Systems

The application of RCM, for the formulation of maintenance programs for developmental systems, is intended to be accomplished through the use of the guidelines set forth in Appendix C to AMCP 750-16, "DARCOM guide to Logistic Support Analysis." To aid in the evaluation of the effectiveness of this approach, the Army selected the AN/TPQ-37 Radar Set (Artillery Firefinder) as its developmental system assessment candidate. The Firefinder System is currently under management control of ERADCOM.

A survey was conducted at ERADCOM to evaluate the RCM program accomplishments on the AN/TPQ-37 Radar Set. The survey included a visit to the Firefinder Project Office located at Fort Monmouth, New Jersey. A discussion with the project office personnel identified several obstacles to the evaluation of RCM application on developmental systems:

1 The Firefinder system is not in the developmental stage but is actually in the low rate initial production phase.

2 Although LSA is a contractual requirement on this system, Appendix C is not an applicable document, since it was not in force at the time the development contract was let.

3 No RCM accomplishments had been reported by the system contractor to the project office at the time of the survey.

The discussion also included the identification of the RCM guideline documents furnished to the contractor, which were the MSG-2 Planning Document and the CERCOM RCM Guide. In addition, limited guidance was provided in the contract statement of work, which specified hard-time component replacement criteria. Finally, the project office personnel indicated their intent to continue to monitor the contractor's RCM activities, as part of future ILS in-process reviews of the Firefinder system. A detailed report of the ERADCOM survey is included as a part of Exhibit IV, CERCOM RCM Survey.

The ERADCOM survey did not result in the identification of specific RCM accomplishments on their developmental system candidate. However, the survey supplemented by past experience on other system developmental efforts, did provide insight relevant to RCM application on new systems:

1 Although Appendix C to AMCP 750-16 meets the requirements for establishing the guidelines for application of RCM principles to maintenance program development for new systems, LSA is not always a contractual requirement. When the LSA is not a specified there, are no alternate RCM program approaches.

2 While LSA usually is specified as a contract requirement on major system development programs, the accompanying FMECA task is often reduced in scope or totally excluded as a supporting requirement. This has been noted in system development efforts by all of the services. Since the RCM concept emphasis is on the use of a FMECA, this total task must be included as a contract data item to enhance the RCM application to developmental systems.

3 ERADCOM personnel did not project an intimate understanding of the RCM concept. Since this was the only research and development command visited, it cannot be explicitly concluded that this is typical of all of the development commands. Higher Army command levels must make certain that RCM training and orientation programs include, not only materiel readiness commands but, research and development organizations.

At this time the impact of RCM on Army developmental systems cannot be measured, since no accomplishments have been noted. The Army should designate, on a priority basis, a major developmental system candidate for RCM application. In so doing it should ascertain that the LSA, supported by a full-up FMECA, is a formal contract data requirement. The Army must also remain cognizant of the need to dedicate monies for these tasks to prevent their curtailment.

3.11 Evaluation of RCM Impact on Army Depots

3.11.1 General

During the visits to the five readiness commands an evaluation was made to determine how depot operations are impacted as the result of implementing RCM related programs on the candidate systems/equipment, i.e., TOW Antitank Assault Weapon System, M-113 Armored Personnel Carrier, UH-1H Helicopter, M-110 Self-Propelled Howitzer, and VRC-12 Radio Set. This

Three on-going programs contained element(s) of RCM (i.e., DMWR Scrub, Oil Analysis, and On-Condition Maintenance for overhaul candidate selection) that when implemented on system/equipment would impact depot operations.

3.11.2 TOW Antitank Assault Weapon System

On-condition selection for overhaul candidate selection does not have application to the TOW system as it does not have a system overhaul requirement. Individual system components are returned to the depot for repair only as a result of field failure. Since on-condition selection is not applicable to TOW, depot operations should not be impacted.

The TOW DMWRs have been prepared for each of those individual system components so that when field failures occur, TOW equipment can be repaired at depot under an IROAN philosophy. The DMWRs contain instructions for fault detection, disassembly, repair and reassembly only to the extent necessary to return the component to condition code A standards.

A formal DMWR scrub has not been accomplished, primarily because MIRCOM's contention that their present maintenance policies are in accordance with RCM principles. However, at MIRCOM's request Anniston Army Depot personnel reviewed the DMWRs. Their recommendations consist primarily of relaxing the criteria for repair of scratches, dents, abrasions, discolorations, and painting preparation requirements for all the system components. These recommendations are being evaluated now by the prime weapon system contractor.

Estimation of the savings to be realized through relaxing of cosmetic requirements has not been made, but probably will result in a minimal impact on depot operations.

Oil Analysis is not a consideration for the TOW system.

3.11.3 M-113 Armored Personnel Carrier

On-condition maintenance for overhaul candidate selection has not been implemented on the M-113. The program for selecting the M-113 family for depot overhaul is expected to be basically the same as for the M-60 family and the results are expected to be comparable.

A pilot on-condition selection program has been implemented on the M-60A1 tanks and the results have indicated approximately 70 percent reduction in the number of tanks selected for overhaul as opposed to the hard-time selection criteria. It is reasonable to expect that the M-60A1 results would be indicative of the results to be expected on other track vehicles. Therefore, it can be expected that overhaul requirement for M-113 armored personnel carriers operated in CONUS may be reduced by a similar percentage. Overseas operational environment and requirements could have a pronounced influence on the number of vehicles selected as candidates for overhaul. There is no data to base an estimate of what this impact would be.

The results of the pilot program through 7/26/78 are: 171 vehicles were subject of the on-condition maintenance inspection, 48 were selected as candidates for overhaul. Thus 28 percent of the vehicles inspected actually require depot overhaul under the present selection criteria.

A DMWR Scrub is in progress on the M-113 DMWRs. There has been no figure computed to indicate what affect the DMWR scrub will have on depot maintenance of the M-113. It will not be possible to obtain an estimate of the DMWR scrub depot impact prior to September, 1978.

Oil Analysis program was implemented on the M-113 family of vehicles during 1976. Since that time there is evidence that in excess of $175,000. cost avoidance was realized. Cost avoidance is computed as the difference in the cost of repair and the cost of depot overhaul of the engines. This cost figure is based on feedback in less than 40 percent of the cases where maintenance was recommended. This would indicate that there is a reduction to be expected in the number of M-113 engines returned to depot in any given year. The precise amount of reduction in engines requiring overhaul could not be predicted from the information on hand.

The status of the M-113 Oil Analysis program is contained in the following matrix.

YEAR	NUMBER OF RECOMMENDATIONS	ACCURATE PROGNOSIS	INACCURATE PROGNOSIS	CUMULATIVE FEEDBACK RPTS	COST $ AVOIDANCE
1976	3	-	-	-	-
1977	86	34	-	55	$ 82,500
1978	142	58	-	139	93,000
TOTAL	231	92	-	139	$175,500

3.11.4 AN/VRC-12 Radio Set

The AN/VRC-12 radio set is subjected to periodic technical inspections as defined in Technical Bulletin TB-750-252. Based on the results of these inspections, when the condition warrants, radios are selected as candidates for overhaul. (Assemblies and subassemblies are forwarded to the depot upon failure.) This inspection meets the requirement of the on-condition selection of equipment for overhaul. Therefore, no additional overhaul selection criteria will be developed for the AN/VRC-12 without which there can be no impact on depot operations.

CERCOM has not implemented the DMWR scrub program on the AN/VRC-12 radio set. It is at present developing plans for such a program which will have as its major emphasis the reduction in cosmetic tasks and requirements for testing. Since the DMWR scrub program has not been accomplished, there is no current estimate of the depot impact. However, by limiting the emphasis to the possibility of elimination of cosmetic repairs and test requirements the impact will be necessarily minimal.

Oil analysis is not a consideration on the AN/VRC-12 radio set.

3.11.5 UH-1H Helicopters

On-condition maintenance was initiated on Army aircraft, including UH-1H helicopter, in 1973. A Aircraft Condition Evaluation (ACE) team of ten men travels annually to on-site locations and inspects all aircraft to determine serviceable condition based on established criteria. The condition reports are forwarded to TSARCOM where the details are weighted for importance and processed through computers to obtain a PI for each aircraft. This PI then becomes the determining indicator for the aircraft's potential candidacy for overhaul at depot.

Since OCM implementation approximately 350 aircraft are being overhauled each year, compared with more than 700 overhauled annually under the previous system using a hard time limit. Not all of this 50 percent reduction is attributable to OCM, however, since all aircraft have experienced less flying hours since 1973, but depot impact from OCM has been considerable nevertheless. If the trend to date is constant for the future, (similar usage and flying conditions) each airframe would be overhauled once in 25 years of service (3500 to 4000 flying hours at 150 hours per year each).

Engine overhaul is currently determined on a hard time limit of 1800 hours usage, plus overhaul is accomplished if the engine is sent to depot for repair (or transferred) when over 50 percent of these hours has been accumulated. A study is underway with the aim of extending these limits upward to 2400 hours and 70 percent respectively, with decisions anticipated in 1979. However, depot activity may not be reduced in direct proportion, since a study of engines sent to Corpus Christi Air Depot (See Attachment 1 to Exhibit I) showed that only 6 percent of engines returned for overhaul had reached the 1800 hour limit. Engine impact on depot can be more accurately determined when results of an AVCO-Lycoming study contract are available at end of FY 78.

DMWR scrub on UH-1H engines is being withheld in order to include information due from the AVCO-Lycoming contract just mentioned. Airframe DMWR's were reworked in 1975 with a new format called Aircraft Depot Maintenance DMWR (ADM-DMWR) which was devised to support the OCM program. Under ADM-DMWR, first implemented in 1976, no assembly or component of the air frame is to be removed or repaired unless it meets a deficiency standard or is removed to facilitate repair of another element or component. A preshop analysis is required for each aircraft and an additional, detailed inspection is required for determination of exact repair/removal action

needed. This program would appear to indicate that depot overhaul requirements would be considerably reduced while depot test work is increased, however, no figures have been made available to evaluate depot impact resulting from initiation of the ADM-DMWR program.

AOAP was first started on Army aircraft equipment in 1957, prior to collection of data on equipment overhauls. Therefore, analysis of the impact that this program had on aircraft depot activity is not feasible. Also, changes to AOAP due to RCM implementation are not anticipated, so depot operations should not be expected to vary beyond those changes experienced when AOAP was activated.

3.11.6 M-110 Self-Propelled Howitzer

On-condition selection for overhaul has not been implemented on the M-110. The program for selecting self-propelled artillery vehicles is basically the same as for the M-60 and M-113 families. Therefore, the information presented for the M-113 is valid for the M-110 and will not be repeated here.

A DMWR scrub program is in progress on the M-110 DMWRs. In 1979, ARRCOM requested Letterkenny Army Depot to recommend changes to M-110 DMWRs based on an inspect-and-repair-as-required (IRAR) basis. The modifications recommended by Letterkenny were incorporated in draft DMWRs without material alteration by ARRCOM, and validation of the drafts is scheduled on ten M-110 units in FY 78. Two of these units were to have been completed in July with an in-process review (IPR) set for 8 August 1978. The IPR should provide information on the scope and suitability of overhaul based on IRAR philosophy. Considerable impact on depot activity from this type of DMWR scrub would appear feasible.

The Oil Analysis program was implemented on the M-110 vehicle in 1976. Since its implementation there is evidence that more than $7,500 cost avoidance was realized, based on feedback in 50 percent of the cases where maintenance was recommended. This would indicate that a reduction is to be expected in the number of M-110 engines returned to depot in any given year. The precise reduction in numbers of engines requiring overhaul could not be predicted from the information on hand.

The status of the M-110 Oil Analysis program is contained in the following matrix.

Year	Number of Recommendations	Accurate Prognosis	Inaccurate Prognosis	Cumulative Feedback Reports	Cost Avoidance
1976	3	—	—	3	$ 7,500
1977	3	—	—	--	—
Total	6	—	—	3	$ 7,500

EXHIBIT I

TSARCOM RCM SURVEY REPORT

SUMMARY

The purpose of this survey was to review the implementation of RCM on the UH-1H Helicopter and determine the adequacy of RCM application: An on-site survey was conducted at TSARCOM Maintenance Directorate for the major data acquisition, and supporting information was obtained through telephone conversations, documentation review and a visit to the 49th Area Maintenance Support Activity (USAR) in Orlando, Florida.

Prior to Department of the Army activation of RCM in 1976, a number of programs had been initiated on Army aircraft to reduce the high cost of maintenance and to retain or improve equipment availability.

1 Army Oil Analysis Program (AOAP) started with aircraft maintenance in 1957 and, due to considerable success and wide acceptance, was extended Army-wide in the early 1970s.

2 On-Condition Maintenance (OCM) was implemented on all aircraft including UH-1H in 1973 and resulted in air frames being overhauled on the basis of condition indicators rather than on the basis of hours flown or calendar time. This program, along with concurrent reduction of average monthly flying activities, has saved approximately $45 million annually in airframes overhauled.

3 Aircraft Depot Maintenance - DWMR (ADM-DMWR) program was a logical follow-on to OCM, and was designed to further reduce depot cost to restore airframes to serviceable condition. This requires a detailed inspection of the aircraft in addition to the usual pre-shop analysis, and it includes the basic premise that removal or repair of an element or component is not authorized unless it meets certain deficiency standards, or is removed for maintenance expediency.

4 Project Inspect is a test designed to validate a program of reduced maintenance activities to obtain accurate and dependable usage data and failure rates, and to observe the resulting aircraft availability delta. The program showed a 74 percent reduction of maintenance manhours per flying hour, a 13 percent drop in maintenance cost per flying hour, and a three percent increase in operational readiness. Determination of maintenance intervals was assisted by use of MAVIS (Model for Analysis of Vehicle Inspection Systems). This project was used as the basis for establishing Phased Maintenance which in 1977 was implemented throughout all aviation operational maintenance levels. Phase Maintenance to date has amounted to revision of the periodic and intermediate inspections and spreading these activities over an 800-hour cycle. Each 100 hour inspection encompasses different work so that the entire aircraft is inspected in 800 hours of flying. Considerable task reductions have been accomplished so far, with more reductions anticipated when daily and special inspections are reviewed.

5 Three level maintenance for Army aircraft replaced the traditional four levels in 1976. It was based on successful trials in Southeast Asia combat operations and was supported by DCSLOG Study in 1974. Organizational Maintenance became Aviation Unit Maintenance (AVUM) and General Support was renamed Aviation Intermediate Maintenance, (AVUM) when the old Direct Support unit was disbanded and its functions were assigned to AVUM and AVIM. It is believed that increased aircraft availability is being experienced through reduced downtime.

TSARCOM personnel take the position that Phased maintenance, supported by the other new programs initiated consitutes conformance to RCM principles by optimizing inspection intervals through computer modeling of accurate field experience data. It is also felt that additional condition monitoring tasks are not as applicable to UH-1 Helicoper operations as to high flying aircraft with larger operating crews.

Listed below are Martin Marietta recommendations pertaining to RCM-and related programs under TSARCOM cognizance.

1 Develop and document an RCM decision logic tree specifically designed for helicopter aircraft that can be used both to provide input to MAVIS programming and to serve as an evaluation tool of MAVIS outputs.

2 Develop DMWR revisions to jet engine overhaul requirements, with changes based on satisfactory results of the AVCO-Lycoming study scheduled to be completed in Fiscal Year 1978.

3 Retain all of the RCM-related programs applicable to aviation equipment that demonstrate success in meeting the RCM primary objective, or which reasonably can be assumed successful if supporting data is unobtainable.

4 Retain the monetary and readiness benefits achieved in PMCS revisions per TM-55-1520-210 PM, with future revisions required to be based on data processed through both RCM logic (UH-1H-specific) and MAVIS.

5 Acquire resources necessary to support the acquisition and enhancement of accurate, dependable, and useful field operating and maintenance data to provide a solid, provable basis for future maintenance planning.

EXHIBIT I

TSARCOM RCM SURVEY REPORT

1.0 BACKGROUND

1.1 Purpose of Survey

The evaluation of the application of RCM principles to the maintenance programming for the UH-1H helicopter by the U.S. Army was the objective of this survey.

1.2 Organizations Surveyed

1 U.S. Army Troop Support and Aviation Readiness Command (TSARCOM), St. Louis, Missouri

2 U.S. Army Reserve 49th Aviation Maintenance Support Activity (AMSA-49A), McCoy Airport, Orlando, Florida.

1.3 Date of Survey

1 Initial (telecon) - 17 January 1978

2 On-site (AMSA-49A) - 9 February 1978

3 On-site (TSARCOM) - 27 February through 2 March 1978

4 Follow-up (telecon) - Intermittent between 14 March and 30 June 1978

1.4 Persons Contacted

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1.5 References

1 Maintenance Concepts and Plans for Army Aircraft, USAAVSCOM, Directorate for Maintenance, 9 January 1976.

2 TSARCOM 750-1(1), Airframe Condition Evaluation Requirements for Army Model UH-1 D/H.

3 MAVIS User's Manual, April, 1976.

4 Field Evaluation of UH-1H Helicopter Inspection Systems (RCA) (Ft. Campbell Test Report), March, 1976.

5 USAAVSCOM Technical Report 75-3 (UH-1H Assessment), April, 1975.

6 HDQA Letter 750-77-1, DALO-SML(M) 5 December 1977

7 DA-OSA Memorandum for Deputy Chief of Staff of Logistics, 15 June 1976.

8 DRCMM-MS Letter (addressed to TSARCOM and MIRCOM), 22 February 1978.

2.0 OBJECTIVES AND SCOPE

This investigation, performed in accordance with requirements established in Task 4.0 of Contract DAAG-39-77-C-0169, was conducted to assess the implementation of Reliability Centered Maintenance on maintenance planning for the UH-1H Helicopter. Additional evaluations were made on RCM-related programs, some of which were initiated on Army Aircraft prior to the advent of RCM. Areas surveyed included directives, regulations, and guidance issued to TSARCOM by higher authority; response and action taken by TSARCOM; contents of RCM and RCM-related programs, and accomplishments achieved in support of the program.

The initial portion of the survey consisted of familiarization with UH-1H systems though review of technical manuals, telecons with TSARCOM personnel to determine apparent RCM status, and in-depth study of documentation pertaining to RCM application on Army aircraft. On-site surveys were conducted primarily at the TSARCOM Maintenance Directorate, St. Louis, Missouri. Preliminary familiarization was conducted at the U.S. Army Reserve 49th Area Support Maintenance Activity, McCoy Airport, Orlando, Florida. Follow up telecons were made between 14 March and 30 June 1978 to clarify points of understanding and to assist with analysis of documentation received during the visit to TSARCOM.

Because AVSCOM (predecessor to TSARCOM) had previously initiated several programs which had similar objectives to RCM, the scope of this survey is necessarily devoted in large part to those RCM-related programs which are being continued in force for aviation systems.

2.1 Discussion

Reliability centered maintenance (RCM), an Army maintenance planning program for retaining inherent equipment reliability with reduced cost of maintenance, is a military adaptation of the MSG-2 system of maintaining commercial aircraft. The system was developed by the Air Transport Association (ATA) and approved by the Federal Aviation Authority (FAA). It has been employed by several air carrier companies since 1970.

When RCM was adopted by DA in Fiscal Year 1976 as a viable system for Army equipment maintenance, a number of projects having the same basic objectives were already in operation for Army aircraft. The Army Oil Analysis Program (AOAP) was implemented by AVSCOM in 1967; On-Condition Maintenance (OCM) was tested in 1972 and implemented in 1973; a DCSLOG study for converting the Army's traditional 4-level maintenance system to 3 levels for aviation support was completed, and implementation authorized by

DA in 1974; and the Aircraft Depot Maintenance DMWR (ADM-DMWR) program to revise and improve the inspection criteria DMWR then being utilized was started in 1975. In addition to these, Project Inspect was initiated in 1971 to evaluate UH-1H helicopter inspection systems, and this test resulted in Phased Maintenance being implemented in January, 1977, to replace the Preventive Maintenance System by optimizing inspection intervals for periodic and intermediate inspections of helicopters.

Recognizing the inordinately high cost of over maintaining aircraft under the previous systems, AVSCOM developed and initiated the above mentioned programs in addition to actively participating in larger scope Army programs such as Equipment Service Criteria (ESC), Logistics Support Analysis (LSA), and Logistics Efficiencies for Increased Army Power (LEAP) Issue 127 of Reduction of Preventive Maintenance Checks and Services (PMCS). Among all of these, however, the two projects which seemed to offer the greatest opportunity for cost benefit were Phased Maintenance in OCM. The following paragraphs include discussions, based on descriptions in Reference 1, of all RCM-related programs pertaining to Army aviation with evaluation of their potential values and relationship to RCM objectives.

3.0 RCM RELATED PROGRAMS

3.1 Army Oil Analysis Program (AOAP)

The Army Oil Analysis Program (AOAP) was implemented by AVSCOM in 1957 for aircraft and has become a vital and dependable method of detecting deterioration in engines, transmissions, rotor gear boxes, and other oil-lubricated assemblies. Samples of lubricating or hydraulic oil are used to identify deterioration inside the item by analysis of the oil for metallic particles such as copper, magnesium, or whatever metal is used in the item under inspection. Samples are taken at periodic intervals based on usage hours, and constitute on-condition maintenance (which should not be confused with OCM for airframes only). Since oil sample analysis can detect degradation and impending failure in the item and thereby avert failure during operation (a principal objective of RCM), it constitutes a form of condition monitoring.

Field maintenance personnel AMSA-49A, Orlando, Florida, advised Martin Marietta investigators that they depend heavily on AOAP to prevent operating failures in helicopters and fixed wing aircraft. Their oil samples are sent to McDill Air Force Base at Tampa, Florida. Laboratory response is rapid and recommendations for assembly removal based on analysis results are followed by AMSA-49A.

The apparent value of AOAP is demonstrated by Army extension of the program to mobile equipment in recent years. Considerable data are available to identify totals of samples taken, percentage of samples showing assembly degradation, etc, but no figures were made available to this survey to form a basis for comparing AOAP results with field experience

prior to program initiation. Cost benefit cannot be accurately estimated since pre-AOAP data has not been located. Army-wide acceptance of the program is a matter of record.

Other aviation programs of smaller scope, such as Integrated Spar Inspection System (ISIS) for rotor blades and Health Indicator Test (HIT) for jet engines, are also related to RCM. They are useful in monitoring equipment operating condition and detecting impending failure between the start of deterioration and actual failure occurrence or time of onset (T_{OS}).

3.2 On-Condition Maintenance (OCM)

On-Condition Maintenance, a more recent innovation in aircraft maintenance activity, is a method for selecting aircraft as candidates for depot overhaul on basis of existing condition annual inspection. Prior to activation of OCM, aircraft were returned to depot for overhaul on a hard time limit basis, that is, automatically when a specified number of flying hours had been logged for the aircraft. Sometimes an aircraft in need of overhaul (practically unusable) could not be sent to the depot because the required number of flying hours had not been reached, whereas other units, having accumulated sufficient flying time, could return to depot regardless of serviceable condition. Under OCM, a mobile Aircraft Evaluation (ACE) team was organized to inspect every Army aircraft at least once each year. Traveling to all operational and training units, the 10-man team conducts on-site inspections of the entire fleet to identify each aircraft's condition under specified procedures for each aircraft type. ACE team inspection results are forwarded to the readiness command (now TSARCOM) where the various condition details are weighted for importance to safety, reliability, and other factors. The weighted factors are processed through computers to obtain a Profile Index (PI) for each aircraft. Aircraft which attain a PI of greater than 150 points (maximum is 1000) are considered candidates for overhaul consideration. Aircraft with the highest PI are selected for immediate overhaul, which is usually accomplished at Corpus Christi Air Depot (CCAD), Texas. Reference 2 gives the requirements for evaluation of UH-1H airframe condition.

Table I-1 displays comparison figures of aircraft overhauls accomplished under the previous hard time limit versus the number overhauled since implementation of OCM. The reduction of 350 overhauls a year (700 under hard time, less 350 with OCM) represents a net savings of approximately $45 million a year, after the ACE team cost (travel, pay, and allowances for 10 men) is subtracted. The entire $45 million savings is not fully attributable to OCM, however, since average annual flying hours per aircraft were also reduced during the same time period of initial OCM application. Quantification of savings relationship for OCM versus reduced flying hours has not been attempted. TSARCOM estimates that the number of aircraft overhauled under OCM is approximately one-half of the number which attain the 150 point candidate threshold each year. Assuming the experience of OCM to date is representative of ensuing yearly activity of the

entire UH-1H fleet, the interval between future overhauls of an average helicopter would approximate 25 years (3500 to 4000 flying hours based on 150 usage hours per year). An individual aircraft that deteriorates to a nonflyable condition prior to ACE team annual inspection, however, can be sent to depot by Aviation Unit Maintenance (AVUM) or Aviation Intermediate Maintenance (AVIM) on special justification, and the depot will determine whether repair or overhaul is needed, according to Aircraft Depot Maintenance (ADM) DMWR policies stated in the following paragraph. Changing from use of hard time limit determinations to the on-condition maintenance decisions utilized in the OCM program has been stated as a desirable objective for RCM.

Table I-1. Aircraft Overhaul Comparisons

HARD TIME LIMIT	OCM SYSTEM	REDUCTION
700 Aircraft overhauled per year	350 Aircraft overhauled per year	$45.5 million (350 x $130,000)
	Cost of ACE Team	<.5 million
	Net Savings	$45.0 million

3.3 Depot Maintenance Work Requirement (DMWR)

A logical follow-on of OCM was to review aviation policies to determine how they affected the degree and extent of depot work for each aircraft received at the depot, and to revise the policies to the extent necessary. To support OCM and its objectives, Depot Maintenance Work Requirement (DMWR) for airframes was revised into a new format and retitled Aircraft Depot Maintenance DMWR (ADM DMWR). Under this plan each aircraft received at depot for repair or overhaul undergoes a task oriented preshop analysis (PSA), results of which dictate succeeding overhaul actions. An additional detailed inspection is also required. The basic premise of ADM DMWR is that removal or repair of an element or component is not authorized unless it meets certain deficiency standards or it is removed as maintenance expedient, i.e., to facilitate repair or removal of another element/-component. Reference 1 (Appendix H) states: "The key to success in achieving a reliability centered overhaul at the most economic cost and maintaining a good quality and safe product is the proper development and disciplined use of control logic in the DMWR. Logic guides the overhaul process through appropriate inspection and tests to assure that maintenance standards are met. When properly developed and followed, such logic will prevent unnecessary disassembly and replacement of parts." It is presumed that the referenced control logic is to be applied at depot maintenance facilities during PSA and task determination. However, Reference 1 does not contain any logic questions, description of basic thrust or type of logic desired, and the data needed to support logic decisions is not identified. Survey questions addressed to these matters and to the

development of comparative analysis data showing potential dollar savings did not yield definitive answers. As of the survey date no figures have been provided to determine the effect on aircraft reliability or cost of aircraft overhaul as a result of ADM DMWR implementation.

3.4 Project Inspect

Project Inspect (Reference 4 and 5) is a test program being conducted in three phases to obtain accurate and dependable data on usage and maintenance of the UH-1H and GH-47 helicopters. Through a contract issued by Army Mobile Research and Development Laboratories (AMRDL), Ft. Eustis, Virginia, to Radio Corporation of America (RCA), data were collected from an accumulation of 38,000 flying hours of 120 helicopters at Ft. Campbell, Kentucky, from 1971 to 1973. Sixty helicopters were tested under Phased Maintenance while another sixty were used as control, i.e., maintenance was conducted through current PMCS policies. Data from the first two phases of Project Inspect were inputed to MAVIS (Model for Analysis of Vehicle Inspection System) for computer calculation of test results. MAVIS usage is detailed in Reference 3. Conclusions and comparative data have been frequently published and are well-known in the Army maintenance community. However, these data continue to provide basic justification for Phased Maintenance as replacement for periodic inspections, and are therefore displayed in Table I-2 as contained in a TSARCOM video presentation. Under periodic inspection the entire aircraft was inspected every 100 hours. Under Phased Maintenance, however, a portion of the aircraft is inspected every 100 hours and an 800-hour cycle is required before inspection of the entire unit is completed. Project Inspect is undergoing Phase III testing at Ft. Hood, Texas, to further validate and justify use of Phased Maintenance for aircraft operating in full field environment.

Table I-2. Estimated Benefits from Project Inspect

	OLD SYSTEM (PERIODIC)	NEW SYSTEM	IMPROVEMENT
MMH/FH	29.63	7.79	21.84 (74%)
Maintenance Cost/FH	$4.97	4.32	0.65 (13%)
Parts Cost (over $200)	2.5 million/ year	1.5 million	1.0 million (40%)
Operational Readiness	76.2%	79.2%	3% increase

MAVIS considers such information factors as total and average flying hours, failure rates, failure modes (limited to maximum of three per assembly, subassembly or component), maintenance costs, and inspection frequencies to compute optimum inspection intervals. This model has an input for criticality of possible item failure, but it does not include condition monitoring as a possible output alternative to scheduling of inspection for failure prevention. The survey investigation developed no information to show use of condition monitoring when the MAVIS ouputs were reviewed by TSARCOM (or AVSCOM) engineering for PMCS revision. However, MAVIS does assist with the determination of when scheduled tasks should be performed.

Phased Maintenance replaced periodic or preventive maintenance services in 1977. The previous periodic inspection (total aircraft inspections every 100 hours) was changed to an inspection cycle of 800 hours, in which a part is inspected each 100 hours, although some parts are inspected only at 200, 400, and 800 hours. The old intermediate inspection was eliminated as unnecessary after deletion of approximately 95 percent of these tasks. The remaining 5 percent were assigned to "special" category to accommodate peculiar maintenance requirements. To date, daily and special inspections have not been processed through MAVIS for task disposition and reassignment.

In 1977, TM-55-1520-210 PMS (Preventive Maintenance Services) was revised and a new manual, TM-55-1520-210 PM (Phased Maintenance), was issued to apply the reduced maintenance system to aviation systems worldwide. A TSARCOM engineering comparison of tasks in the new versus the old manual is shown in Table I-3.

Table I-3. Task Comparison

Inspection Interval	Old Manual (Preventive Maintenance)	New Manual (Phased Maintenance)	Reduction
100 hours	990 (complete aircraft)	699 (reduced scope)	291
Intermediate (25 hours)	1,903	0	
			1,806
Special (not regular interval)	*	97*	
Daily	*	*	*
800 hours	5,941	5,593	340

*TSARCOM anticipates additional reduction in maintenance tasks by application of MAVIS to daily and special inspections.

3.5 Three Level Maintenance

Three Level Maintenance is another innovation in aircraft maintenance, designed to produce better maintenance support at the operating/organizational level. It was first tested in Southeast Asia under combat

operations in 1969 to reduce downtime of operational aircraft and thereby increase operational availability. TSARCOM's videotape presentation stated that records of the First Cavalry showed that operational readiness increased from 64 percent to 85 percent and that average monthly aircraft usage went up from 63 to 88 flying hours. In 1974 a DCSLOG study of the plan was released and Department of the Army approved changeover that same year.

The basic concept of three level maintenance is to increase organizational level maintenance capability by reassignment of more than 50 percent of the functions, equipment, and skills normally found in Direct Support Units (DSU). The more complex DSU tasks were reassigned to General Support Units (GSU), along with respective personnel skills, equipment, and facilities. The expanded organizational level was renamed Aviation Unit Maintenance (AVUM), and GSU was redesignated as Aviation Intermediate Maintenance (AVIM). Cost reduction in overall maintenance has apparently been accepted as factual due to the elimination of DSU. Also, it is generally believed by the Army that reduced aircraft downtime in being experienced since program implementation in 1976. Data to support these beliefs has not been published to date. However, both cost reduction and increased operational readiness are directly related to RCM aims and objectives.

4.0 RCM APPLICATION TO UH-1H HELICOPTER

The TSARCOM commander and his predecessors at AVSCOM have taken the position that Army aviation's initiative in developing and utilizing the above mentioned RCM-related programs, plus participation in larger scope Army programs (ESC, LSA, LEAP, and PMCS reduction), constitutes conformance to the principles, concept, and strategy of RCM as directed by the Army and guided by DARCOM. This position has been supported by Reference 6 and also by letter from the Assistant Secretary of the Army (Installations and Logistics) in regard to new aircraft and good progress noted on fielded aircraft. This letter (Reference 7) also states that additional improvement was felt to be attainable.

Personnel within the Maintenance Engineering Division, Directorate for Maintenance, primarily the New Equipment and Maintenance Standards Branch (DRSTS-MEN), are directly involved with RCM by assignment. The Chief of DRSTS-MEN has been designated as RCM Action Officer and aerospace engineers in this branch have developed the correlations between Phased Maintenance and RCM. Special RCM tasks have been distributed among these engineers with one having the OCM program, another having PMCS revision responsibility, another being responsible for MAVIS coordination, and a fourth being involved with DMWR scrubbing. Pertinent engineering data from Project Inspect are available to all engineers and are utilized thoroughly.

In response to DARCOM letter (Reference 8), a failure mode and effects analysis (FMEA) was developed for the following six representative maintenance significant items (MSI) on the UH-1H helicopter:

1 Jet Engine, T53-L-13B

2 Main Rotor Hub, 204-012-101-5

3 90 Degree Gear Box, 204-040-012-7/-13

4 Scissors Pivot, NAS 464P-8/-69

5 Synchronized Elevators, 205-030-856-19/-21

6 Servo Valve Power Cylinder, AN 175H16.

The engineering data (failure rates, failure modes, time of onset, (T_{OS}), and usage hours) needed to prepare the FMEA were obtained from Project Inspect and MAVIS output. Regardless of the varying complexity of the six representative MSIs only three failure modes were available for each system, assembly, or component, due to limitations of the computer model. Also developed for each MSI was a Fault Detection and Location Analysis which was based partially on engineering documentation and partially on the engineers, personal UH-1H experience. These efforts have been hampered by lack of complete, definitive, and procedural guidance from higher command. The efforts have also been limited by lack of dependable data on maintenance experience when conducted under actual field operating conditions. Acquisition of accurate quantitative field failure data regarding components and assemblies, which constitute the majority of MSIs, is a costly and time consuming task; and usually has been performed perfunctorily by AVUM personnel in TO&E organizations. Although it is AVUM which can most benefit from complete RCM implementation, AVUM personnel are not trained in data collection discipline. Their prime interest is directed toward aircraft operational readiness rather than documentation of failure reasons, underlying causes, fault detection methods, and times required for corrective/preventive maintenance. Because of this, available field information is therefore not considered sufficiently accurate for revision of PMCS manuals for aircraft. Hence, TSARCOM is dependent on Project Inspect/MAVIS data, personal knowledge of aircraft maintenance problems, and engineering judgment judiciously applied.

Guidelines from higher commands on implementation of RCM for first line, fielded aircraft and aviation items have been fragmented, and in many cases, undefined and susceptible to varying interpretations. During one six month period TSARCOM was instructed to compare RCM with MAVIS results for frequency of inspections, and then to use DARCOM-developed decision logic; the Assistant Secretary of the Army (Reference 7) recommended that TSARCOM continue on its current course with MAVIS as effectively accomplishing RCM strategy. No flow charts or direct procedural instructions were received, but validation meetings were held for sequencing of maintenance actions under Phased Maintenance. Guidance from the TSARCOM Directorate for Maintenance indicated that the lack of redundancy for Army single engine rotary wing aircraft renders RCM less valid than comparable MSG-2 logic applied to commerical airline equipment. Also, nap-of-earth

(NOE) flying of helicopters restricts addition of condition monitoring tasks to the two-man UH-1H crew, although such tasks may be valid for larger high-flying airline crew operations. Therefore, TSARCOM feels that Phased Maintenance is more adaptable to aviation maintenance than RCM and that it fits RCM objectives as defined to date.

Currently it is TSARCOM's intention to use MAVIS for revision of daily and special inspections, and to conduct a study to more accurately compare RCM with Phased Maintenance. DRSTS-MEN indicated interest in preparing a a large effort on RCM implementation when dependable field data are obtained (subject to personnel resources availability). Current resources are insufficient for a complete RCM effort in addition to Phased Maintenance activities already programmed.

TSARCOM considers the ADM-DMWR program constitutes completion of DMWR-SCRUB requirements for airframe. Revision of jet engine DMWR (T53-L-13B for UH-1H) is presently awaiting receipt of engine overhaul data. A contract awarded to AVCO Lycoming is designed to accumulate data on engine wear levels, failure rates, appropriate repair procedures, and other pertinent details. This information is due at the end of Fiscal year 1978. Close coordination with Corpus Christi Air Depot (CCAD) is being effected to make the AVCO Lycoming study fully cost-effective. During this same period studies are being conducted to review TSARCOM policies established for engine overhaul hard time limit. The current limit is 1800 flying hours, at which time an engine is returned to depot for overhaul. There is also an established policy that if an engine is returned to depot for repair when more than 50 percent of the 1800 hours has been accumulated, it will be overhauled instead of repaired. The studies are intended to consider raising the 1800 hour limit to 2400 hours and the 50 percent factor to 60 or 70 percent. (This 50 percent factor also presently applies if the aircraft is transferred to another unit.) The attachment contains information that directly applies to these policies and revisions being considered. This information indicates that less than 6 percent of engines being received at depot have attained 1800 hours flying time, whereas 25 percent of engines received at depot do not require depot capability for repair. This information supports TSARCOM decision to develop more definitive information prior to revision of jet engine DMWR.

5.0 ASSESSMENT

To accomplish a critical appraisal of maintenance planning for the purpose of understanding or interpreting its relationship to RCM, or to be used as a guide for future action, it is necessary to consider the following solvent factors that are generally considered applicable to RCM today:

1 A formal, positive, restrictive definition of RCM has not been established by the Army or DoD.

2 The principles of MSG-2 are considered to be the basis of RCM strategy and concept.

3 The primary objective of RCM is to retain inherent equipment reliability at the lowest overall cost.

4 To achieve this objective, some or all of the following elements may be included:

a Engineering analysis of historical equipment data

b Processing data through decision logic

c Eliminating unnecessary maintenance tasks

d Replacing hardtime criteria with on-condition inspection or condition monitoring

e Replacing on-condition inspection with condition monitoring

f Adding new maintenance tasks only if they are cost-effective

g Restoring inherent equipment reliability (by PMCS or overhaul)

h Reducing maintenance tasks (PMCS and overhaul)

i Reducing maintenance costs (PMCS and overhaul).

An objective analysis of TSARCOM maintenance planning activities in relation to RCM implementation for aircraft indicates that through participation in RCM related programs, the objective elements delineated above have been accomplished in varying degrees. Itemized assessments regarding TSARCOM accomplishment of each element are given below.

Engineering Analysis (a, above)

Engineering analysis on Project Inspect data was performed by RCA, through exercising of MAVIS, for revision of intermediate and periodic PMCS. Similar analysis of historical data of fielded equipment has not been attempted, except for a token effort on six representative MSIs of UH-1H.

Decision Logic Processing (b, above)

Specific decision logic has not been developed for the UH-1H helicopter, and the DARCOM-developed logic has not been applied per se. However, certain decision logic points, such as criticality for safety, have been entered into MAVIS computation manually, and MAVIS output has been evaluated by TSARCOM engineers on the basis of personal judgment. The resulting answers could have paralleled or equal value to protential answers obtainable through decision logic usage.

Eliminating Unnecessary Tasks (c, above)

The extent of accomplishment in this area is unknown. It is assumed that the maintenance tasks shown as eliminated in Paragraph 3.5 and Table 3 were considered unnecessary. However, information necessary to justify such deletions or retention of tasks was not available to this investigation. Due to errors of interpretation of RCM procedures the results of performing FMEA and FADALA on six UH-1H MSIs were inconclusive. Martin Marietta processing of these six items through RCM processes indicated a potential benefit if condition monitoring was used for determining out-of-adjustment failures on the scissors pivot sleeve assembly and on the power cylinder servo valve (cyclic and collective cylinders). However, this also was not conclusive due to insufficient data.

Replacing Hard Time Criteria with On-Condition Inspection or Condition Monitoring (d above)

MAVIS is designed to quantify inspection intervals for determination of optimum frequency. Replacement of hard time limit with on-condition inspection is an option of engineering review of MAVIS output. It was assumed that some hard time limits were replaced with on condition inspection where appropriate. Condition monitoring has not been considered to be a viable alternative for UH-1H helicopter in TSARCOM determinations.

Replacing On-Condition Inspection with Condition Monitoring (e, above)

Condition monitoring has not been accepted by TSARCOM as a viable replacement for on-condition tasks in PMCS revisions on UH-1H. TSARCOM reasoning in this matter is covered in Paragraph 4.0.

Addition of Cost-Effective Maintenance Tasks (f, above)

No evidence has been produced to show the addition of a PMCS task that could be cost effective by preventing deterioriation or reducing corrective maintenance through any of the RCM related programs. It is possible that all such feasible additions have been accomplished previously, due to analysis and corrective action on field operating problems.

Restoring Equipment Reliability (by PMCS or Overhaul) (g, above)

Considerable progress in this area is evidenced by field testing and determination of operational readiness. Project Inspect, Phased Maintenance, OCM, ADM DMWR, and other programs have contributed to retention of inherent equipment reliability.

Reduction of Maintenance Tasks (PMCS and overhaul) (h, above)

PMCS tasks have been reduced drastically for 25 hour (intermediate) inspections and for 100 hour (periodic) inspections. In addition, the

scope of each 100 hour inspection has been made much smaller, resulting in reduction of tasks over 800 hour phasing. Depot tasks should have been reduced considerably, due to ADM DMWR for airframes, but comparison to prove this has not been feasible to date. Reduction of engine overhaul tasks has not been attempted to date.

Reducing Maintenance Costs (PMCS and Overhaul) (i, above)

Some success in this area is documented and accepted by Department of the Army. With the program actions taken by Army aviation commands, cost of PMCS is assumed to be less than under previous systems, and savings from OCM program appear valid. However, additional savings are believed to be possible through adoption of some RCM methodology in support of currently implemented programs.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Implementation of RCM on the UH-1H helicopter cannot be denied or accepted categorically. Due to lack of establishment of a formal definition of RCM there is no firm standard or scale of measurement to quantify the degree of RCM implementation achieved on UH-1H. When such definition is developed and supported with measureable goals and required procedures, a more direct and conclusive answer will be feasible.

There is little doubt that RCM on UH-1H helicopters has only minor similarity to MSG-2 processes. TSARCOM has taken the position that MSG-2 is not as effective as MAVIS in helicopter maintenance operations; thus no effort has been expended to develop an MSG-2 type logic for UH-1H.

It is also obvious, however, that the primary objective of RCM (Paragraph 5.0) has been attained on UH-1H to a large degree. All of the RCM related programs currently applicable to UH-1H maintenance activities have been designed and implemented to address either one or both portions of RCM's primary objective, and progress toward that objective has been noted. Success in this direction provides the most positive support of the TSARCOM position on accomplishment of RCM.

In regard to the nine items delineated as RCM elements in Paragraph 5.0, approximately 50 percent have been accomplished in UH-1H maintenance programming. Three of these would have to be graded as more than 50 percent accomplished, three graded less than 50 percent, two split in half; and one item has unknown accomplishment for grading.

6.2 Recommendations

Based upon the information, assessment and conclusions contained in this exhibit the following recommendations pertaining to UH-1H are tendered by Martin Marietta to the Army:

1 Develop and publish a formal RCM program that is fully defined with measurable goals and established procedures.

2 Develop guidance and instructional courses for the benefit of readiness command RCM personnel to eliminate, insofar as possible, interpretation differences and lack of understanding.

3 Require the development and documentation of an RCM decision logic tree specifically designed for helicopter aircraft that can be used both to provide input to MAVIS programming and to serve as an evaluation tool of MAVIS outputs.

4 Consider the ADM-DMWR program for aircraft as satisfactory accomplishment of DMWR scrubbing for airframes. Require similar DMWR revisions to jet engine overhaul requirements to be based on satisfactory results of the AVCO-Lycoming study scheduled to be completed in Fiscal Year 1978.

5 Retain all of the RCM-related programs applicable to aviation equipment that demonstrate success in meeting the RCM primary objective, or which reasonably can be assumed successful if supporting data is unobtainable.

6 Retain the monetary and readiness benefits apparently achieved in PMCS revisions per TM-55-1520-210 PM with future revisions required to be based on data processed through both RCM logic (UH-1H - specific) and MAVIS.

7 Support the acquisition and enhancement of accurate, dependable, and useful field operating and maintenance data to provide a solid, provable basis for future maintenance planning.

REFERENCES

1. USAAVSCOM, Directorate for Maintenance, 9 January 1976.
2. TSARCOM 750-1(1), Airframe Condition Evaluation Requirements for Army Model UH-1 D/H.
3. MAVIS User's Manual, April, 1976.
4. Field Evaluation of UH-1H Helicopter Inspection Systems (RCA) (Ft. Campbell Test Report), March, 1976.
5. USAAVSCOM Technical Report 75-3 (UH-1H Assessment), April, 1975.
6. HDQA Letter 750-77-1, DALO-SML(M) 5 December 1977
7. DA-OSA Memorandum for Deputy Chief of Staff of Logistics, 15 June 1976.
8. DRCMM-MS Letter (addressed to TSARCOM and MIRCOM), 22 February 1978.

EXHIBIT II

MIRCOM RCM SURVEY REPORT

AD-A063 559 MARTIN MARIETTA AEROSPACE ORLANDO FLA F/G 5/1
RELIABILITY CENTERED MAINTENANCE STUDY.(U)
SEP 78 R TIPTON, R BOEMLER, J ROBINSON DAAG39-77-C-0169
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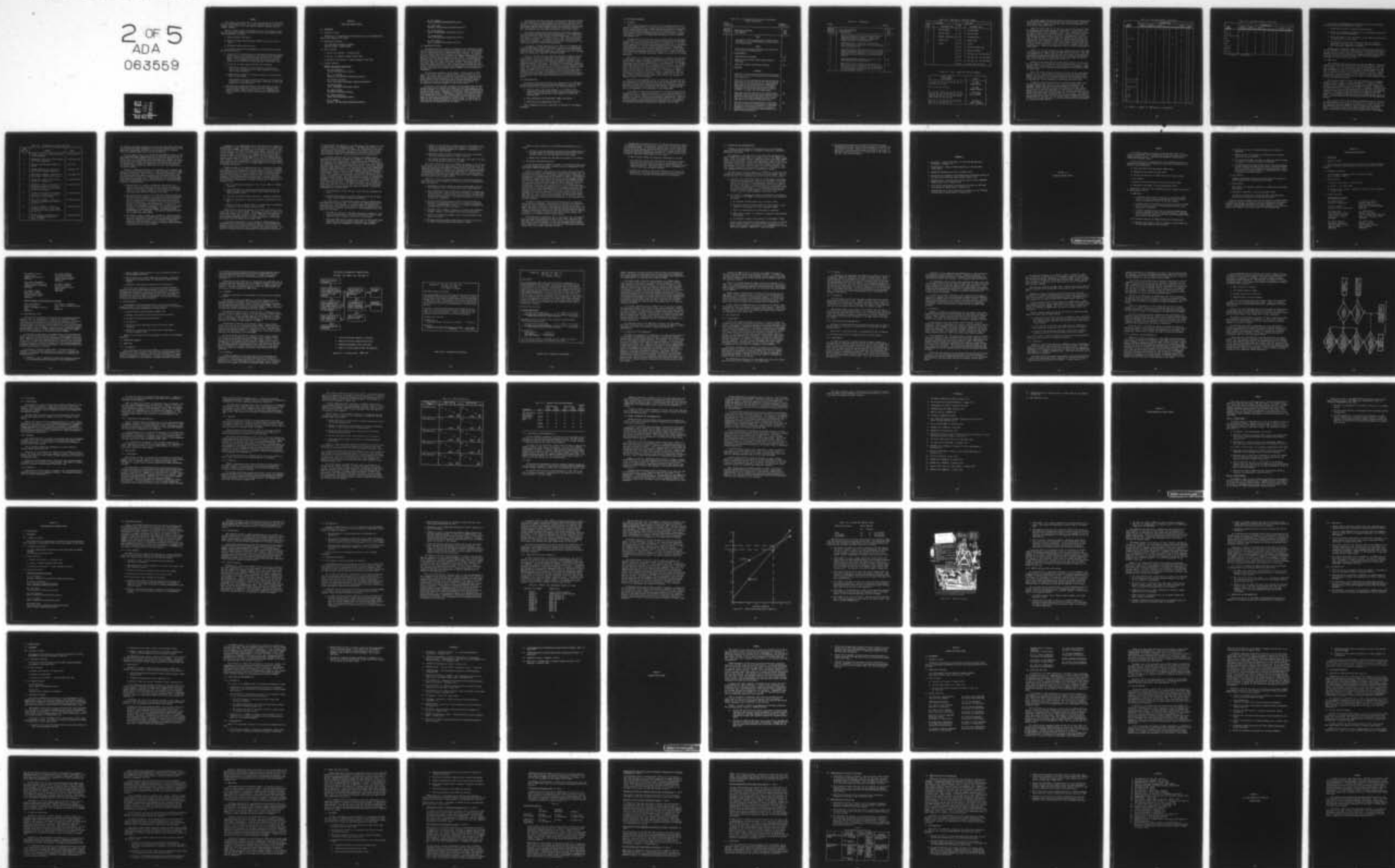


SUMMARY

The intent of this survey was to review the application of RCM principles to the TOW Weapon System. An on-site inspection was held 27 February through 3 March 1978, at U.S. Army Missile Readiness Command, Redstone Arsenal, Alabama.

Since no formal program for RCM application to the TOW Weapon System has been developed by MIRCOM, related RCM activities were analyzed. The areas studied were as follows:

1 Technical Manual (TM) Review

2 Depot Maintenance Work Requirement (DMWR) and depot work policy review

3 Maintenance Engineering Activities

The following significant recommendations have been made concerning RCM related activities:

1 A study of the revised preventative maintenance checks and services (PMCS) tables in the TOW Operator's and Organizational Maintenance Manual revealed that no RCM based logic was used in the revision effort. It is recommended that PMCS be revised using draft DA pamphlet "Guide to RCM for Fielded Equipment," dated April 1978.

2 A review of the depot program indicated the following:

  a TOW items are returned to depot primarily on the basis of failure and repaired only to the extent necessary to restore them to code A standards.

  b DMWRs reflect changes in tolerances compared to original specification requirements.

  There appears to be little additional benefit to be derived from continuation of the DMWR scrub program. Therefore, it should be regarded as a completed effort.

3 The maintenance engineering personnel have developed solutions to field reported problems that reflect principles related to RCM decision making. Based on these results, it is recommended that review of reported field failures be subjected to RCM logic processing.

EXHIBIT II

MIRCOM RCM SURVEY REPORT

1.0 BACKGROUND

1.1 Purpose of Survey

Evaluation of the application of RCM principles to the TOW Weapon System was the purpose of the survey.

1.2 Organization Surveyed

U.S. Army Missile Readiness Command
Redstone Arsenal, Alabama 35809

1.3 Date of Survey

1 Initial (via telecon) - 19 January 1978

2 On-site - 27 February through 3 March 1978

3 Follow-up (via telecon) - 6 March through 21 April 1978

1.4 Persons Contacted

MIRCOM - Maintenance Directorate

Mr. Harold Barnard
Writer, TOW Publications Section

Mr. L. D. Brantley
Engineer, TOW Maintenance Engineering Section

Mr. William P. Burnett
Chief, Land Combat Maintenance Engineering Division

Mr. David Gardner
Chief, TOW/DRAGON Publications Section

Mr. Wayne Hollaway
ILS Office - RCM Action Officer

Mr. Robert Hutchinson
Chief, LCSS Publications Section

Mr. S. LaCaze
Engineer, TOW Maintenance Engineering Section

Mr. Paul Newman
Chief, TOW/SHILLELAGH/DRAGON/LCSS Branch

Mr. Robert Sams
Engineer, TOW Maintenance Engineering Section

Mr. Warren Shelton
Chief, FARR/CHAPARRAL Publications Section

Mr. Joseph Watson
Chief, TOW Maintenance Engineering Section

Mr. John Wiggins
Chief, Technical Publications Divisions

2.0 OBJECTIVES AND SCOPE

The MIRCOM survey was conducted in compliance with Department of the Army (DA) contract DAAG-39-77-C-0169, Assessment of the U.S. Army Implementation of Reliability Centered Maintenance (RCM) (Reference 1), which was let to the Martin Marietta Corporation in Orlando, Florida. The specific objective of this survey was to evaluate the command's implementation of RCM on the TOW Heavy Antitank/Assault Weapon System. The applicable system equipment items include the launch tube, optical sight, missile guidance set, traversing unit, tripod, and battery assembly and the mounting kits required to adapt the system to tactical vehicles. Pursuant to this effort, RCM related activities on other systems managed by MIRCOM were identified. These additional activities are highlighted in this report only to the extent necessary to accurately reflect MIRCOM's total RCM program accomplishment.

The survey was conducted in three phases - initial contact by telephone, 5-day on-site survey at Redstone Arsenal, and follow-up by telephone. The initial contact was made to: (1) establish a point of contact between Martin Marietta Corporation and MIRCOM, (2) make MIRCOM aware of Martin Marietta's role within the scope of the RCM assessment contract, (3) obtain an overview of the RCM activities within the command, and (4) establish a firm time schedule for the on-site survey.

The on-site survey included interviews with personnel within the Maintenance Directorate to identify the elements of their RCM program for the TOW Weapon System, the problem areas encountered in program implementation, and the achieved results. Research of the RCM data files was undertaken to identify all significant correspondence, directives, and guidance relevant to the MIRCOM RCM activity. The follow-up phase of the survey provided a means for clarifying the information discussed during the personal interviews and data accumulated during the on-site survey. It also served to bridge the gap between developments occurring during the time of the on-site survey and the preparation of this report.

The reception received on-site was friendly and the RCM Action Officer for the directorate, Mr. Wayne Hollaway, was extremely cooperative during the visit. The primary working groups involved in RCM activities (i.e., publications and maintenance engineering personnel) generally did not seem to be overly familiar with the basic concept and underlying principles of RCM. Nevertheless, they willingly participated in the survey effort.

The initial conversation with Mr. Hollaway and subsequent meetings with other directorate personnel included discussions on the command definition of RCM and its basic position on RCM implementation. It was felt that RCM was a concept that in effect states: "Don't perform more maintenance than is necessary." In addition, the feeling is that the concept should only be applied to developmental systems since implementation costs would be too high for fielded system application.

In relating to command implementation for RCM on the TOW Weapon System, it became readily apparent that there is presently no comprehensive, formalized RCM program being conducted. In addition to the directorate's professed lack of available manpower and funds required for such a program, there are perhaps more significant existing problems.

There is a definite need for formalized guidance for RCM application to be supplied, not only to MIRCOM but to all commodity commands. This guidance must include RCM decision logic and complete, detailed instructions as to its application. An additional problem was evident in the preparatory phase of this survey. The directorate was asked to identify a number of maintenance significant items (MSI) on the TOW Weapon System and to perform a failure mode effects and criticality analysis (FMECA) on these items. The response was that they did not have sufficient data or resources available within the directorate to comply with this requirement. A FMECA is one of the vital input ingredients in any RCM program; and, until the expertise required to perform this type of analysis is developed, any attempt at formal RCM program implementation would be severely handicapped.

3.0 RCM APPLICATION

Although no formalized RCM program was implemented on the TOW Weapon System, the Maintenance Directorate has been engaged in significant RCM related activity for this missile system. The activities include:

1 Technical Manual (TM) Review Program, i.e., revision of the operator/crew preventive maintenance checks and services (PMCS) table, including integration of the equipment serviceability criteria (ESC)

2 Depot Maintenance Work Requirement (DMWR) Scrub Effort

3 Sound Maintenance Engineering Practices.

These independent efforts are described and assessed in the ensuing paragraphs.

4.0 RCM RELATED PROGRAMS

4.1 TM Review

The TM review program was initiated on the TOW Weapon System in response to a DARCOM directive to revise the PMCS and eliminate the ESC manuals as separate publications. DARCOM issued this directive by transmittal letter to all commodity commands on 2 June 1976 (Reference 2). The TM review program for the TOW Weapon System was started by MIRCOM in October 1976, prior to release of the DARCOM RCM Implementation Plan in December 1976 (Reference 3).

Personnel from the Publications and Land Combat Maintenance Engineering Divisions of the Maintenance Directorate collaborated on the TM review program. The technical writers developed the new PMCS table in TM 9-1425-470-12, Operator's and Organizational Maintenance Manual for the TOW Weapon System (Reference 4). It was reviewed and approved by the maintenance engineering personnel based on their engineering judgment. No RCM based logic was used in support of the PMCS revision effort. It is the opinion of the directorate personnel that there basically is no change in the overall content of the scheduled maintenance program as a result of the revised PMCS table.

The results of the PMCS revision effort, as reflected on the TM review accomplishment report from MIRCOM to DARCOM dated 8 February 1978 (Reference 5), show a dramatic increase from 8 to 103 items. These results are misleading in that the revised PMCS table is the product of: (1) integrating of ESC with the PMCS and (2) reformatting the old PMCS. The old PMCS table is included in this survey report as Table II-1 for reference purposes. The new PMCS table is incorporated in Reference 4. A summary of the old and new tables is shown in Table II-2. As indicated, a major portion of the new table includes the addition of mounting kit items for all vehicles designated for TOW usage. This, coupled with the fact that many of the old items included multiple checks, belies the increase in number of items in the new tables.

The TM review accomplishment report of 8 February 1978 indicated the unavailability of pertinent information on the old and new PMCS. For example, annual manhour requirements for performing the old PMCS and the new PMCS were not given and the estimated annual manhours actually expended by field personnel under the old PMCS were not specified. Absence of this data is an impediment to the assessment of the revised PMCS.

In an effort to assess the effectiveness of the PMCS revision and ESC integration effort, a comparative analysis of the old and new tables is included in the report. Each of the 103 items in the new tables can be accounted for in the old tables and the ESC Manual (Reference 6). Table II-3 shows the results of this comparison and lends credence to the contention of the directorate maintenance engineering personnel that the content of the scheduled maintenance program was not impacted by the new PMCS.

Table II-1. Old-Operator/Crew Preventive Maintenance Checks and Services

D–Daily
Time required: 1.5

W–Weekly
Time required: 0.8

Interval and Sequence No. D	W	ITEM TO BE INSPECTED PROCEDURE	Work Time (M/H)
		NOTE The procedures in this table are for equipment which is in continuous use. Refer to paragraph 3-5J for interval or preventive maintenance of equipment maintained in a state of operational readiness.	
		NOTE The word replace in the following procedures indicates a need for exchange of the item or for maintenance by the direct support unit.	
		ALL EQUIPMENT	
1		Inspect and clean all equipment.	0.2
2		Inspect for missing or loose, cracked, ripped, distorted, or broken parts.	0.2
	1	Remove rust, corrosion and spot paint as required.	0.5
		LAUNCHER	
		CAUTION Humidity causes degradation of detector elements. Therefore, the humidity indicator should be utilized as an indication of optical sight moisture content. Minimize optical sight to humidity exposure.	
3		Check and replace the optical sight by contacting the direct support contact team if the 30 percent sector of the humidity indicator is white or pink; the eye guard is not in good condition; reticle light and focus control do not work; AZIMUTH and ELEVATION adjustments knobs and covers are damaged or inoperative; focus control binds; damaged optics or electrical connector; or no image can be seen through eyepiece.	0.1
3.1		Check night sight for no reticle illumination; RANGE FOCUS, CTRS, BRT controls do not work; optics or electrical connector damaged; no image appears in sight. Perform steps 12.1, 12.3, and 12.4 of table 2-6 and, if malfunctions still exist, replace night sight by contacting direct support contact team.	0.3
4		Check the desiccant in the missile guidance set. If the 40 percent sector of the humidity indicator is white or pink, replace the desiccant in accordance with paragraph 3-7.1. Inspect missile guidance set case to insure that it is not punctured or cracked; that the cover fits tight and latches properly. If not, replace the missile guidance set.	0.2

Table II-1. (Continued)

D–Daily W–Weekly

Interval and Sequence No. D	W	ITEM TO BE INSPECTED PROCEDURE	Work Time (M/H)
	2	Remove the battery assembly from the missile guidance set. Clean and dry the battery compartment. Replace missile guidance set if electrical connector in compartment is damaged or if spring is missing or inoperative.	0.3
5		Inspect the breech area of the tube. Replace the tube if any scratches, gouges, or worn spots have penetrated through one layer of fiberglass cloth.	0.1
6		Inspect the muzzle area of the tube. Replace the tube if any damage has penetrated through the wall of the tube or if any damage has penetrated approximately one-third of the thickness of the reinforcing ring (thick area on the forward tip of the tube).	0.1
7		Inspect the tube. Replace the tube if any cracks or if any clearly visible raised area can be detected.	0.1
8		Inspect tripod to make sure that level indicators are not broken, that each leg will extend fully, that the detent stop levers operate properly, that the leg locks work, and that the feet and anchor claws are operational. Replace the tripod if these requirements are not met.	0.2

Table II-2. PMCS Tables - Breakdown Summary

OLD PMCS		NEW PMCS	
STEP NO.	EQUIPMENT ITEM	STEP NO.	EQUIPMENT ITEM
1-2	All Equipment	1-3	All Equipment
3	Optical Sight	4-10	Optical Sight
4	Missile Guidance Set	11-20	Traversing Unit
5-7	Launch Tube	21-24	Launch Tube
8	Tripod	25-31	Tripod
		32-39	Missile Guidance Set
		40-44	Battery Assembly
		45-51	M232 Mtg. Kit (1/4 Ton Veh)
		52-56	M236 Mtg. Kit (1/4 Ton Veh)
		57-77	M225 Mtg. Kit (1/2 Ton Veh)
		78-103	M233E1 Mtg. Kit (APC)

Table II-3. PMCS - Comparative Analysis Summary

REVISED TABLE STEP NUMBER	SOURCE
4-8, 20, 23, 24, 26-31, 35, 36, 39, 42, 44, 50, 55, 76, 102	Old PMCS (Daily Checks)
3, 43, 51, 56, 77, 103	Old PMCS (Weekly Checks)
1, 2, 9-12, 14-19, 21, 22, 25, 33, 34 37, 38, 40, 45, 46, 49, 52, 53, 57, 58, 61, 67, 68, 70, 71, 74, 75, 78, 79-82 89-93, 95, 96, 98, 99, 101	ESC Manual (Red Criteria)
13, 32, 41, 47, 48, 54, 59, 60, 62-66, 69, 72, 73, 83-88, 94, 97	ESC Manual (Amber Criteria)

To further assess the revised tables, the items that were derived from the ESC red and amber criteria were put into a matrix format to highlight their disposition. Tables II-4 and II-5 show the red and amber ESC criteria source items respectively.

Table II-4 shows items 10, 16, and 53 as the only red condition items not designated for a combat operability check (COC). Item 10 deals with the optical sight and its cleanliness. Due to the criticality of the optical sight function and the possible effects of dirty or clouded lenses, consideration should be given to item 10 as a COC candidate. Item 16 is also critical in that it is associated with alignment of the launch tube line of sight and optical line of sight. It should therefore be given consideration as a COC candidate. Item 53 is a missile rack item which provides for storage of missiles on the 1/4 tone missile carrier vehicle and is similar to the function of item 61 (red criteria: stowage of less than three missiles). Based on this similarity, item 53 should be designated as a COC item.

Items 2, 45, 52, and 78 deal with urgent Modification Work Order (MWO) incorporation on the weapon system end items and mounting kits. Only item 45 is designated as a Before Operation Check (BOC) item. There should be consistency in assessing this category of items (urgent MWO incorporation), all of which should be classified identically; i.e., delete the BOC for item 45 or add the BOC for items 2, 52, 57, and 78.

Analysis of the amber condition items listed in Table II-5 shows all but item numbers 62-66, 83-88, 94, and 97 as designated BOC items. Investigation shows these items are associated primarily with equipment stowage functions and, as such, indicates proper rationale for exclusion of a BOC for these items.

Table II-5 further indicates items 32 and 41 as the only items designated for a COC. Item 32 deals with cracked azimuth and elevation meter windows, and item 41 deals with missing fasteners for the battery assemblies. Since neither of the items is critical to system operation, it is recommended that the COC designation be eliminated for these items.

In addition to the TM review effort on the TOW Weapon System, other land combat system PMCS tables have also undergone revisions such as CHAPARRAL, DRAGON, FAAR, and Land Combat Support System (LCSS). The CHAPARRAL, DRAGON, and FAAR revisions had no impact on the PMCS tables. This was due to a previous independent revision exercise, requested by TRADOC, which already minimized the PMCS. The revision effort on the LCSS showed significant impact in reducing PMCS (68 to 45 steps). The reduction was more significant than indicated since previously nonexistent ESC was incorporated with the PMCS. All the section chiefs indicated that the PCMS revision efforts were intended to be one-shot exercises with no provisions for sustaining review efforts.

Table II-4. ESC Red Criteria - Disposition

STEP NUMBER	DISPOSITION						
	BEFORE OPERATION	DURING OPERATION	AFTER OPERATION	WEEKLY	MONTHLY	COMBAT OPERABILITY	TYPE CHECK*
1	X	X	X	X		X	O
2						X	M
9	X			X		X	I
10	X	X	X		X		C
11, 12, 14	X					X	O
15	X	X		X		X	O
16	X				X		I
17, 19	X					X	I
21	X					X	O
22	X					X	I
25	X			X		X	O
27, 28	X					X	O
33, 34	X			X		X	O
37, 38	X					X	O
40	X	X		X		X	O
45	X					X	M
46, 49	X					X	I
52						X	M
53	X						I
57						X	M
58, 61, 67, 68	X					X	I
70, 71, 74, 75	X					X	I
78						X	M
79-82, 89, 90	X					X	I
91, 92	X					X	O
93	X					X	I
95, 96	X					X	O
98, 99	X					X	I
101	X					X	O

* C = Clean, I = Inspect, M = MWO Status, O = Operational

Table II-5. ESC Amber Criteria - Disposition

STEP NUMBER	DISPOSITION						
	BEFORE OPERATION	DURING OPERATION	AFTER OPERATION	WEEKLY	MONTHLY	COMBAT OPERABILITY	TYPE CHECK*
13	X				X		O
32, 41	X				X	X	I
47, 48, 54, 59	X				X		I
60	X				X		I
62-66					X		I
69	X				X		I
72, 73	X				X		O
83-88					X		I
94, 97					X		I

* I = Inspect, O = Operational

As a result of investigating the TM review effort on the TOW Weapon System the following conclusions are offered:

1 No RCM logic was used to support the PMCS revision

2 Little or no guidance was available to the Maintenance Directorate at the time of the TOW TM Review

3 The review effort was not performed to reduce PMCS but primarily to incorporate ESC into the tables

4 The designation of the ESC criteria into the check intervals specified in the PMCS tables, are proper from the standpoint of good engineering judgment and consistency.

Although good engineering judgment was utilized in the integration of ESC into the PMCS, no evidence of the application of RCM guidelines and logic was apparent in the overall revision effort. Therefore, it is recommended the revised PMCS be reviewed by the Maintenance Directorate personnel using the draft DA pamphlet "Guide to RCM for Fielded Equipment," scheduled for release in mid April 1978.

4.2 DMWR Scrub

This command was directed to revise or scrub the DMWRs on a pilot program which was eventually identified as the TOW Weapon System. From the time of issue of the turn-on directives from DA and DARCOM until the present, differences in position have been readily apparent between the command and DARCOM as to the need for scrubbing of the TOW DMWRs. In an effort to accurately describe the activities related to this pilot program and to make an accurate assessment of the overall TOW depot maintenance program, the significant related events as shown in the chronology in Table II-6 are individually addressed.

The DA message dated 4 February 1977 and addressed to all commodity commands (Event 1) called for the establishment of a program to perform in-depth reviews of DMWRs to achieve compatibility with RCM and the issuance of interim guidance to the depot/industrial complex. Subsequently the DARCOM message of 22 February 1977 (Event 2) requested a milestone plan for review of at least one high-overhaul-cost end item from each commodity command to include time frames, methodology, and validation procedures. At a directors of maintenance meeting held at this command in April 1977 (Event 3) the TOW Weapon System was selected as the MIRCOM pilot study program. This essentially was the initiating activity for the TOW DMWR scrub program.

Mr. J. Watson, chief of the maintenance engineering section for TOW at the MIRCOM Maintenance Directorate, and members of his staff are firm in the conviction that this command is now and always has been compliant with the underlying principles of RCM in regard to their depot maintenance policy. It has been stated that the overall MIRCOM depot maintenance policy is basically in concert with the principles of RCM. (For example,

Table II-6. TOW DMWR Scrub Program Chronology

EVENT REF. NO.	SUBJECT	DATE
1	DA MSG: Reduction of Depot Maintenance Work Requirements	4 February 1977
2	DARCOM MSG: Reduction of Depot Maintenance Work Requirements	22 February 1977
3	Directors of Maintenance Meeting at MIRCOM	April 1977
4	DARCOM/DESCOM Review of TOW Weapon System Reconditioning Operations	9 November 1977
5	MIRCOM MSG to DARCOM: Application of RCM to DMWRs, MIRCOM Position Letter	30 November 1977
6	DARCOM MSG: Request for Briefing to DARCOM on TOW DMWR Review	14 December 1977
7	DARCOM MSG: Request for Assistance to AMRSA Representative on Review of Mechanical Portion of Missile DMWRs at Anniston Army Depot	19 January 1978
8	Internal Correspondence (Maintenance Directorate to TOW Project Office): Application of RCM to DMWRs	24 January 1978
9	Trip Report (MIRCOM): Briefing to DARCOM on TOW DMWR Review (Event Reference No. 6)	30 January 1978
10	Trip Report (AMRSA): Review of Mechanical Portion of Missile DMWRs at Anniston Army Depot (Event Reference No. 7)	6 February 1978
11	MIRCOM Message to Hughes Aircraft Corp.: Recommended Changes to Ground TOW DMWRs	9 February 1978

all commodity items are supported at the depot under the inspect and repair only as necessary (IRON) philosophy.) Mr. Watson alluded to the fact that maintenance requirements are often defined through military standards which, if reviewed, might lead to cost saving benefits.

Mr. Paul Newman, chief of the TOW/SHILLELAGH/DRAGON/LCSS Branch of the Land Combat Maintenance Engineering Division, reaffirmed the stand that the directorate is in full compliance with the principles of RCM and has no need to enter into a separately identifiable DMWR scrub program. He stated further that any RCM based program should be thoroughly field tested prior to implementation. Finally, Mr. Newman believes that RCM has a place in new systems being developed but would prove too costly for implementation on fielded systems.

Meanwhile, DARCOM has held firm in its contention that savings to the Army can be realized through application of RCM principles to missile DMWRs and depot work policies. In an effort to resolve the differences in position between MIRCOM and DARCOM, a review of the TOW Weapon System reconditioning operations (Event 4) by DARCOM/DESCOM was held at Anniston Army Depot (ANAD) on 9 November 1977. A major portion of the review included a briefing of DARCOM/DESCOM personnel by ANAD personnel. The briefing highlighted the following points:

1 Reconditioning, as applied to maintenance work on TOW, is in reality most closely associated with the elements of inspect and repair. Specifically, TOW items are fault isolated and disassembled only to the degree necessary to return them to code A standards (operating condition, issuable to the user).

2 The principal items involved in the TOW reconditioning program are the M220 launcher, composed of five secondary items on which there are twelve field replaceable subcomponents; and the M70 trainer, which is composed of nine secondary items having seven field replaceable subcomponents. In addition; there is a battery charger having five field replaceable subcomponents. A total of 38 separate and programmable items make up the TOW launcher and training system. The various subcomponents are tested and repaired in accordance with their applicable DMWRs. The MIRCOM document, USAMICOM-DMRL 750-7 (Reference 7), includes the complete reference list of TOW Weapon System DMWRs.

3 The TOW depot repair programs are performed in a bay-style operation where disassembly is performed only to the extent necessary to facilitate inspection and repair. The reconditioning process includes the supporting quality control functions of inspection, verification test, and final acceptance of material being performed at appropriate points in the process.

Subsequent to the DARCOM/DESCOM review, MIRCOM initiated a message to DARCOM (Event 5), dated 30 November 1977, on the application of RCM strategy principles to DMWRs. The purpose of this message was to establish the official position of MIRCOM on the DMWR scrub program. Reference was made to the 9 November 1977 review of the TOW Weapon System reconditioning operations at ANAD. The position of the command and depot personnel was averred at that time and conveyed the idea that the principles of RCM were already incorporated into the TOW DMWRs and, in fact, all MIRCOM-managed depot programs. Since no objection to this position was interposed at the time of the review by either DARCOM or DESCOM representatives, the command recommended that not only TOW, but all MIRCOM DMWRs, need no further review to meet RCM requirements.

DARCOM responded to the MIRCOM position with a message on 14 December 1977 (Event 6). The message conceded recognition of electrical components being repaired based on condition. However, DARCOM felt potential existed for applying RCM principles to the mechanical areas of missile equipment. Therefore they requested a MIRCOM briefing be given to their associate director of material management on the study and conclusions relative to the DMWR review conducted on the TOW Weapon System. The tentative date for the briefing was established for 27 January 1978 and was to address the following items:

1 Use of manufacturing tolerances in lieu of wear limits or overhaul tolerances

2 Fixed requirements for teardown and component repair in lieu of preshop analysis or partial teardown to determine condition and need for further repair

3 Correction of cosmetic defects unrelated to equipment reliability

4 Mandatory replacement of items not supported by experience or test data

5 Return of missile system end items for overhaul based on individual condition in lieu of complete system overhaul.

DARCOM issued an additional message on 19 January 1978 (Event 7) concerned with review of missile DMWRs. The message indicated, as part of the ongoing RCM program, that a review of current DMWRs was being conducted on a spot basis to determine documents in need of revision. A request was made to provide MIRCOM assistance to a MRSA representative in performing the subject review at ANAD on 24-25 January 1978.

To satisfy the requirements of the December 14 DARCOM message, the MIRCOM Maintenance Directorate requested the ANAD to review TOW DMWR work practices to specifically identify potential changes or modifications to standards criteria that would result in manpower and material savings. The results of the ANAD review were documented by the Maintenance Directorate

in their internal correspondence to the TOW Project Office (Event 8), dated 24 January 1978. The suggested changes to TOW DMWRs were centered on relaxation of criteria for scratches, dents, cuts, discoloration, and painting preparation requirements. The specific TOW hardware items included were the optical sight, missile guidance set, instructor console, power supply modulator, battery, tripod, mounting kits, and target source.

In further compliance with the 14 December 1977 DARCOM message, Mr. Wayne Hollaway made a presentation to DARCOM on the TOW Weapon System DMWR review on 26-27 January 1978. The presentation was summarized in Mr. Hollaway's trip report dated 30 January 1978 (Event 9). The presentation highlighted the MIRCOM overhaul/rebuild concept on major end items and secondary items (down to printed circuit card level). No existing requirement for system rebuild exists. The presentation specifically highlighted changes to DMWR 9-1450-470-1 for carrier, guided missile equipment which redefines the rebuild criteria for the TOW-M233E1 mounting kit (adaption of the TOW Weapon System to the M113, APC). The changes specify that wear limits, fits, tolerances, and allowable corrosion will be based on the operation of functional units and visual inspection instead of conforming to equipment drawing 10189546, which delineates new mounting kit hardware requirements. This change was implemented prior to November 1976, which actually preceded the start of the DMWR scrub program. Mr. Hollaway concluded that a detailed look at TOW DMWRs did produce some improvements on mechanical items, but the cost to study all existing program requirements would exceed any potential savings that might be realized. His specific recommendations are listed below:

1 The requirements for the TOW pilot study should be considered complete.

2 A detailed RCM analysis of existing programs should not be implemented without attendant manpower and funding.

Mr. Virgil Pucket of the maintenance support branch of MRSA visited ANAD between 23-26 January 1978. As a result of the DARCOM message dated 19 January 1978, he was assigned to review TOW DMWRs and cosmetic work being performed. The results of Mr. Puckett's visit are summarized in his trip report dated 6 February 1978 (Event 10). The highlights of that trip report are as follows:

1 TOW DMWRs are written on individual components as opposed to a complete system level basis. The repair and overhaul program is also funded on an end item basis rather than a total system.

2 Individual DMWRs include complete repair data for TOW Weapon System components, but final appearance requirements are included in a general DMWR which encompasses all missile system equipment.

3 Evidence of the application of RCM principles in the DMWRs is prevalent, as evidenced by the various changes in tolerances on repaired and overhauled equipment as compared to requirements on procurement specifications.

4 Touring the repair facilities revealed little if any unnecessary work being performed purely for cosmetic purposes.

5 The working principles applied on TOW appear to be used on all missile system equipment being worked at ANAD.

The latest significant event in the DMWR scrub program, as of the time of the survey trip, was the correspondence from the TOW Project Office to Hughes Aircraft Corporation (HAC) on 9 February 1978 (Event 11). This correspondence addresses the feasibility of incorporating recommended changes to the ground TOW DMWRs as cited in the memorandum of 24 January 1978 from the Maintenance Directorate to the TOW Project Office. HAC has been requested to review these proposed changes and provide their recommendations for incorporation to the project office.

Based on a review of available documentation and contact with directorate personnel, the following conclusions are relevant to TOW DMWRs and depot work policies:

1 Requirements are often defined by general missile DMWRs and military standards which, if reviewed, may yield economic benefits.

2 The reconditioning policy on TOW consists primarily of inspect and repair operations. Items are generally returned to the depot based on field failure. Returned items are fault isolated and then disassembled and repaired only to the degree necessary to restore the item to code A standards.

3 The TOW reconditioning program includes not only end items but secondary or subcomponent items which are reworked in accordance with their individual DMWRs. There is no existing requirement for reconditioning on a total system basis.

4 TOW DMWRs reflect changes in tolerance on repaired and overhauled equipment compared to procurement specification requirements.

5 Little or no unnecessary cosmetic work is being performed on TOW items at the depot.

6 The good working principles being applied on TOW are also used on all missile system equipment being returned to ANAD.

Based on these conclusions, the following recommendations are offered:

1 A review of military standards and general missile DMWRs which define maintenance and work requirements should be identified and reviewed as part of an overall depot work scrub program.

2 DARCOM should consider the TOW DMWR scrub program to be complete.

4.3 Maintenance Engineering Practices

In discussing specific hardware problems on the TOW Weapon System with maintenance engineering personnel, potential areas for application of the principles of RCM were manifested.

There is a resolver noise problem in the optical sight which results in failure of self-test step number seven on the missile guidance set. The excessive noise generated in the resolver assembly results in degradation in range due to increased wobble of the missile in flight. The problem was determined to be correctible by removal of the resolver assembly end cap, spraying with common tuner cleaner, and blowing out the assembly with dry air. Had this failure mode (dirty resolver) been subjected to RCM logic, it would have resulted in either condition monitor (detectable by an unsteady meter indication by the operator); or, if the failure mode were unacceptable, an on-condition inspection and cleaning at the direct support facility would have been performed based on an interval dictated by the frequency of the failure mode. Based on an annual failure return of approximately 200 resolver assemblies, a 90 percent reclaim factor, and an estimated unit cost of $215, a potential annual savings of approximately $43K (less the cost of inspection and cleaning) can be realized. Use of RCM logic would have facilitated the identification of this inspection and cleaning technique.

The battery charger utilized on the TOW system gives no indication that batteries are charging. Incorporation of indicators for current and voltage are being considered to facilitate monitoring by the operator. Again, this solution would have become apparent through application of this item to RCM logic. The output of the logic process would have resulted in redesign incorporating indicators to facilitate condition monitor, based on a tradeoff of criticality (reliability and safety) versus economic consideration, or on-condition test to detect failure.

The NI-CAD battery replacement rate is increasing. This is primarily due to the batteries reaching their end of life. Due to the short time span from onset of deterioration to actual failure, this battery failure mode may be a potential problem. If this were determined through application of RCM logic, a tradeoff decision of hard time replacement versus condition monitor for failure would have resulted.

The maintenance engineering section for TOW has demonstrated, through a recommended solution of the resolver noise problem, a direct application of the RCM philosophy. The additional examples cited on the battery charger and the NI-CAD battery identifies other potential areas for RCM application. The referenced problems are the result of a cursory review of the TOW Weapon System that demonstrates potential for economic benefits and an increase in operational effectiveness of the system.

In view of these findings the following recommendations are made:

1 The directorate should give consideration to developing RCM decision logic or utilizing existing logic for application to TOW equipment problems as they are identified through feedback from the using organizations. This application of RCM is recommended in lieu of a full scale system-wide program.

2 The RCM logic should be exercised by TOW maintenance engineering personnel or individuals possessing comparable expertise on the weapon system to maximize the effectiveness of the program.

5.0 CONCLUSIONS AND RECOMMENDATIONS

Although no formal program for RCM application to the TOW Weapon System was developed by MIRCOM, it did engage in significant independent RCM-related activities.

The evaluation of the RCM effort on the TOW system highlighted two major problem areas which appear to be common to all of the commodity commands. There is an urgent need for formalized guidance from higher command levels for the application of RCM, including decision logic and detailed implemention instructions. Additionally, MIRCOM has indicated that it does not possess the resources necessary to perform a FMECA. The results of this analysis are a vital input in support of a total RCM program. Until this analysis capability is acquired, the capability to develop an effective comprehensive RCM program will be significantly limited.

The RCM-related activities engaged in by MIRCOM on the TOW system were performed in response to directives received from DA and DARCOM. The following conclusions and recommendations on these activities were reached:

1 Analysis of the revised PMCS table in the TOW Operator and Organizational Maintenance Manuals indicates accomplishment of ESC integration into the PMCS in a logical manner. However, the application of decision logic or other RCM guidelines was not a part of the effort. Therefore, the revision cannot be realistically claimed as an RCM accomplishment. It is recommended, therefore, that the PMCS be redone through application of the draft DA pamphlet "Guide to RCM for Fielded Equipment," dated April 1978.

2 As a result of reviewing the technical documentation and RCM file data peculiar to TOW DMWRs and ANAD work policies, the following is concluded:

a The equipment reconditioning policy is based on IRON.

b The depot program is based on repair of field failures in subassemblies in accordance with their individual DMWRs.

c There is no requirement for system rebuild or overhaul.

d DMWRs reflect changes in tolerances as compared to specification requirements.

e No unnecessary cosmetic work appears to be performed at ANAD.

Based on these observations, there appears to be little or no additional potential benefit to be derived from continuation of the depot review program. Consequently, it is recommended that the TOW DMWR scrub program be regarded as a completed effort.

3 The maintenance engineering personnel have displayed, through recommended solutions to field reported problems, a potential area for application of RCM. Based on this observation, it is felt the application of reported failure modes, occurring in the field, to RCM logic should be included as an integral part of the review process for field related problems.

REFERENCES

1. DA Contract: DAAG-39-77-C-0169, U.S. Army RCM Implementation Assessment, 23 August 1977.

2. DARCOM Message: Review of PMCS/Integration of ESC with PMCS, 2 June 1976.

3. DARCOM RCM Implementation Plan, 28 December 1976.

4. TM 9-1425-470-12 Operators' and Organizational Maintenance Manual for TOW Heavy Antitank/Assault Weapon System, January 1974.

5. MIRCOM Message: Technical Manual Review Results on TOW, CHAPARRAL, DRAGON, FAAR, LCSS; 8 February 1978.

6. TM 9-1425-470-ESC Equipment Serviceability Criteria for TOW Heavy Antitank/Assault Weapon System, 15 March 1976.

7. USAMICOM DMRL 750-7, *Depot Maintenance Reference List for* TOW Heavy Antitank/Assault Weapon System, 1 February 1974.

EXHIBIT III

TARCOM RCM SURVEY REPORT

SUMMARY

The TSARCOM reliability centered maintenance (RCM) survey was to conduct an assessment of the implementation of RCM principles to the M113 Armored Personnel Carrier. Interface with TARCOM was accomplished by on-site and telephone contact.

Since the M113 was not representative of the TARCOM RCM effort, an analysis was performed on the following six RCM related programs that are currently being implemented:

1 Depot Maintenance Work Requirement (DMWR) Scrub

2 Equipment Serviceability Criteria (ESC)

3 On-Condition Selection of Combat Vehicles for Depot Overhaul

4 Oil Analysis

5 Reduced Preventive Maintenance Checks and Services (PMCS)

6 Reliability Improvement of Selected Equipment (RISE)

Significant conclusions and recommendations that resulted from a study of these programs follow:

1 DMWR Scrub

a A procedure manual should be prepared for conducting a DMWR scrub on tank and automotive vehicles other than the M113 to utilize the expertise obtained on the M113 program.

b A program should be developed to periodically reassess the DMWR which includes the effect of engineering decisions on depot maintenance requirements.

c To realize maximum benefits from the program the DMWR program should be expanded in scope to determine economical substitute actions that would result in lower cost while maintaining safety and reliability design levels.

2 On Condition Selection of Combat Vehicles for Depot Overhaul

a Decision logic should be used to establish a uniform basis for decision making among various personnel.

b Catastropic failure or accidental damage action should be addressed.

c Methods need to be developed for establishing the numerical values for each key indicator.

d The critical threshold, that point at which the vehicle becomes a candidate for overhaul, should be established.

e A comparison should be made between results of preshop analysis and the condition indicated in the vehicle condition evaluation report to validate the on-condition selection criteria. After the criteria is proven satisfactory, consideration can be given to dropping the preshop analysis.

3 Oil Analysis

Feedback requirements stated in TB 43-0210 should be enforced to ensure feedback from all maintenance facilities.

4 Reduced PMCS

More orderly and systematic planning at headquarters-levels should be effected.

5 Reliability Improvement of Selected Equipment (RISE)

If RISE is a candidate for future application, AMC Regulation 702-15 should be revised to include RCM principles.

None of the above programs employ the application of the RCM principle of engineering analysis. Without at least one comprehensive RCM program there is no way to gage the benefits that may be accrued or to judge whether a comprehensive RCM effort would produce additional cost effective results when compared to the present level of RCM implementation.

EXHIBIT III

TSARCOM RCM SURVEY REPORT

1.0 BACKGROUND

1.1 Purpose of Survey

The evaluation of the application of reliability centered maintenance principles to the M113 Armored Personnel Carrier was the object of this survey.

1.2 Organization Surveyed

U.S. Army Tank - Automotive Material Readiness Command
Warren, Michigan 48090

1.3 Date of Survey

1 Initial (via telecon) - 7 January 1978

2 On-Site - 13-17 March 1978

3 Follow-up (via telecon) - Intermittent between 27 March 1978 and 28 April 1978.

1.4 Persons Contacted

Maintenance Directorate

Col. Richard Bryant
Director of Maintenance

Mr. M. M. Cieslak
Deputy Director of Maintenance

Mr. George Dodd
M113 Maintenance Mechanic
Combat Vehicle Division
Tracked Vehicle Branch
DRSTA-MCB

Mr. Thomas Franquist
Mechanical Engineering
Systems Support Division
Analysis Branch
DRSTA-MSA

Mr. Gerald B. Gladieux
Equipment Specialist
Tactical Vehicle Division
Heavy Tactical Vehicle Branch
DRSTA-MVB

Mr. Thomas Hackett
Equipment Specialist
Special Purpose Vehicle Division
Construction Equipment Branch
DRSTA-MVB

Mr. Charles Jones
RCM Action Officer
System Support Division
Analysis Branch
DRSTA-MSA

Mr. Luther T. Friday
Division Chief
Combat Vehicle Division
DRSTA-MC

Capt. Dennis Kagzkowski
Special Project Officer for Implementation of CVM Study
DRSTA-MRM

Mr. Joseph J. Kovac
M548 Vehicle Manager
Combat Vehicle Division
Tracked Vehicle Branch
DRSTA-MCB

Mr. George McDermott
M113 Vehicle Manager
Combat Vehicle Division
Tracked Vehicle Branch
DRCPM-M113

Mr. Robert Tannahill
Mechanical Engineer
System Support Division
TMDE Branch
DRSTA-MST

Product Manager, M113/113A Family of Vehicles

Capt. John Fieberger
Logistic Officer
Logistic Management Division
M113
DRCPM-M113

Mr. Richard G. Snodgrass
Chief Logistic Manager Division
M113
DRCPM-M113

2.0 OBJECTIVES AND SCOPE

This survey was performed in accordance with the requirements established in Task 4.0, subparagraph a, of DA Contract DAAG-39-77-C-0169 (Reference 1). The objective was to evaluate the application of reliability centered maintenance (RCM) to the M113 Armored Personnel Carrier. Related programs initiated before RCM formalization, as well as the formalized RCM program, were evaluated in the survey. Areas investigated included requirements issued to TARCOM by higher authority, response of TARCOM to RCM requirements, contents of RCM and RCM-related programs, and achievements in the implementation of RCM and RCM-related programs.

In pursuing the evaluation of the TARCOM effort in the implementation of RCM on the M113 Armored Personnel Carrier, it became apparent that the effort expended on the M113 was not representative of TARCOM's RCM achievements. Numerous RCM related programs have been initiated over a wide range of vehicles. To ignore the work accomplished on other tank and automotive products would provide a distorted picture of the RCM program achievements at TARCOM. Therefore the survey was expended to cover all RCM effort, with specific attention given to the M113.

The survey was conducted in three parts: an initial survey via telephone, an on-site survey consisting of a 4-day visit to TARCOM, and a follow-up via telephone. The initial survey was made to accomplish the following results:

1 Establish a line of communication between Martin Marietta Corporation and TARCOM personnel responsible for RCM implementation

2 Apprise TARCOM of Martin Marietta's role and objectives under DA contract DAAG-39-77-C-0169

3 Become familiar with recent TARCOM RCM developments, current program status, and future plans for continuing to expand the RCM program

4 Establish a time frame for conducting the on-site survey

The on-site survey consisted of interviews with TARCOM personnel associated with RCM and RCM-related programs to identify accomplishments and problems associated with each area of RCM application. Research to determine what requirements, guidelines, and instructions have been given to TARCOM and analysis of TARCOM's responsiveness to the requirements, guidelines and instructions was also undertaken. Follow-up was conducted to clarify and obtain additional information.

3.0 RCM APPLICATION

A comprehensive RCM program has not been initiated on any tank or automative product. Instead, the RCM effort here consists of the following six RCM-related programs, implemented in varying degrees:

1 Depot Maintenance Work Requirement (DMWR) Scrub

2 Equipment Serviceability Criteria (ESC) Manual Elimination

3 On-Condition Depot Maintenance Selection

4 Oil Analysis

5 Reduced Preventive Maintenance Checks and Services (PMCS) Screening

6 Reliability, Availability and Maintainability Improvement of Selected Equipment (RISE)

Results of the evaluation of these programs are given in the following paragraphs.

4.0 RCM-RELATED PROGRAMS

4.1 DMWR Scrub

4.1.1 Requirements

Depot Maintenance Work Requirement (DMWR) is a document that explicitly specifies the scope of depot or contract maintenance operations to be performed on an item of equipment, types and kind of material to be used, quality of workmanship, repair methods, procedures and techniques, modification requirements, fit and tolerances, equipment performance parameters

to be achieved, quality assurance discipline, and other essential factors that prescribe maintenance operations to ensure an acceptable and cost-effective product as the result of overhaul. The DMWR is prepared in accordance with the contents of Military Specification MIL-M-63041B (Reference 2).

DA Message DA 042225 (Reference 3), establishes the requirement that an in-depthh review and subsequent revision of DMWR be perfomed to achieve compatability with RCM. This direction was followed by a DARCOM message (Reference 4), that directed TARCOM to select at least one high-overhaul cost end item on which to perform the DMWR review.

4.1.2 Response

TARCOM has responded to the requirement by initiating a pilot program on the M113.

Food Machinery Corporation (FMC) was contracted (Reference 6) for a two-phase program for reviewing and revising the M113 DMWR as part of a Rebuild Cost Reduction Program. Phase I included establishing a rationale for reducing maintenance actions and producing marked-up DMWRs. Phase II of the FMC effort included validating the marked-up DMWRS on two M113 vehicles and effecting further economic reductions where possible.

Engineering Work Directive No. 070-807-100, Rev. 2 (Reference 7) was issued to revise the Phase II effort to include employment of RCM principles and their use as a guide to develop logic for task elimination or reduction. In addition, it directed their employment as an objective in preparing the revised DMWRs. FMC was directed to assess the real cost savings that would be achieved through changes to the DMWRs.

Food Machinery Corporation has developed a decision logic diagram (Figure III-1) for use in screening the present DMWRs. Application of the logic to any overhaul task would allow selection of one of four possible alternative maintenance categories: elimination of task, condition monitoring task, hard time limit task, or on condition task. This logic has been applied in the development of the draft DMWRS.

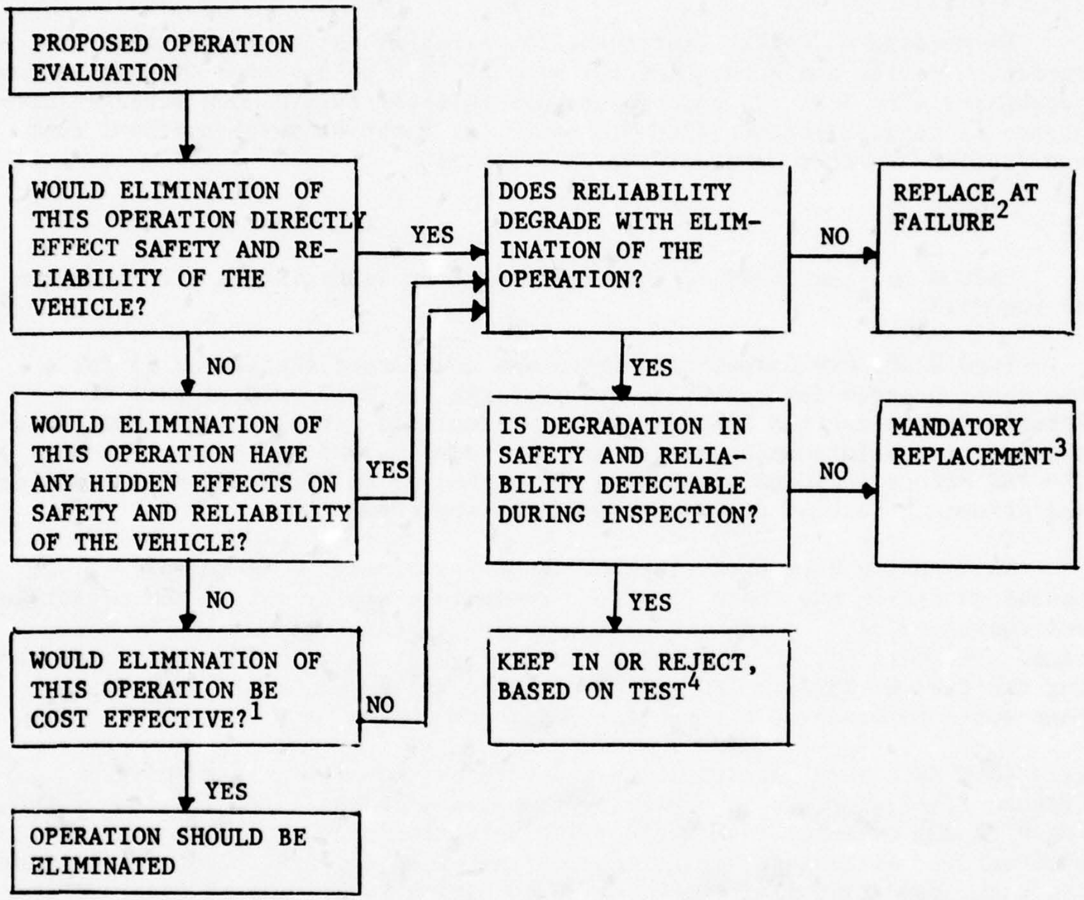
FMC has developed estimated cost reduction analysis sheets (Figures III-2 and III-3) in response to the requirement for an estimate of real cost savings resulting from application of RCM to depot overhaul. These analysis sheets are prepared for each task that changes as the result of the DMWR scrub. Estimated manhours are shown for performing the task under the old DMWR method and for performing the task under the revised method. Numerical differences in manhours between the two methods is also shown. These cost figures are estimates and not real times obtained from depot operations.

4.1.3 Evaluation

Although the DMWR scrub effort was directed by the DA Message of 4 February 1977 (Reference 3) and DARCOM Message dated 22 February 1977 (Reference 4), these documents did not give a clear picture of what was to be done and how. Their requirements were not made clear until a meeting at TARCOM on 19-20 September 1977 when Mr. Eastwood, AMRSA, and Dr. Gordon,

RCM APPLIED TO OPERATION IN DMWR OF M113A1

FMC CORP., ORD. ENGRG. DIV., SAN JOSE, CA



1. Cost Effectiveness (Negative or Positive)
2. Replace at Failure (Condition Monitored)
3. Mandatory Replacement (Hard Time Limit)
4. Keep In or Reject Based on Test (On-Condition)

Figure III-1. Decision Logic - DMWR Scrub

Prepared by: FMC Corp. Ord. Engr. Div.
San Jose, CA 95108
T. E. Simon/ S. Emerson

Road Wheel and Idler Arm Hubs

Per existing DMWR, all road wheel arm and idler arm hubs must be prelubed with grease prior to reassembly. Currently, the method of prelube is by manually loading grease into the hub before assembly to the arm. This method is not totally effective due to the grease voids created by the hand pack, thus the lack of grease in these voids is a contributing factor in reduced bearing life.

A new FMC design pressurized grease prelube fixture will result in a more effective prelube as well as reducing the time spent in the prelube operation. This will result in the reduction of labor costs as well as a better end product.

Estimated Cost Analysis:

Old DMWR Method	
Hand Pack Prelube .083 Hrs/Hub x 12 Hubs	1.0 Hr/Veh
New Method	
Pressurized Fixture .033 Hrs/Hub x 12 Hubs	0.4 Hr/Veh
Total Est	0.6 Hr/Veh

Figure III-2. Estimated Cost Analysis

Prepared by: FMC Corp. Ord. Engr. Div.
San Jose, CA 95108
T. E. Simon/ S. Emerson

Final Drives

Per existing DMWR, 100% of the vehicle final drive assemblies are being disassembled and overhauled. FMC estimates that during average cyclic overhaul of vehicles, 60% of final drives could have operated satisfactorily without overhaul. One problem is that no effective preshop techniques had been developed for checking assembled final drives in or out of the vehicle.* These preshop tests were developed by FMC's gear train and maintenance specialists and added to DMWR scrub draft. Certain tests, including a crack/leak red dye check test, reveal existing or potential final drive problems, thus allowing 60% of final drives not to be disassembled or removed. The former 100% ZYGLOW requirement mandated by DMWR due to cracks found in some housings could be satisfied by the red dye test procedure and seal leakage problems could be essentially eliminated.

Estimate Cost Analysis:

Existing DMWR Method

(2) Final Drive ZYGLOW Check	0.4 Hr @ 100% x 2	0.8 Hr/Veh
(2) Final Drive Teardown/Build-Up	4.5 Hr @ 100% x 2	9.0 Hr/Veh
Final Drive Total Est. Labor (Overhaul)		9.8 Hr/Veh

*New DMWR Scrub Method (Based on 40% requiring Teardown/Overhaul After 100% Preshop Testing)

(2) Final Drive Red Dye Test	0.2 Hr @ 100% x 2	0.4 Hr/Veh
(2) Final Drive Teardown/Build-Up	4.5 Hr @ 40% x 2	3.6 Hr/Veh
Final Drive Total Est. Labor (Overhaul)		4.0 Hr/Veh

Cost Reduction

Existing Method	9.8 Hr/Veh
(New Method)	(4.0 Hr/Veh)
Est. Cost Savings	5.8 Hr/Veh

*If final drives need not be removed from the vehicle for preshop test, an estimated greater cost reduction will occur.

Figure III-3. Estimated Cost Analysis

DARCOM, presented a detailed briefing of RCM principles and implementation plans. The absence of regulations, explicit instructions, and guidelines from higher headquarters has resulted in confusion among those charged with the responsibility for reviewing and revising the DMWRs.

The decision logic created for the scrubbing of the DMWRs (Figure III-1) has been restricted to the elimination and reduction of overhaul tasks contained in the present documents. While the elimination of some items and the reduction in scope of others is essential, other considerations not covered in the logic offer possibly greater economic benefits. Establishment of overhaul tasks and procedures in the DMWR and its supporting, documents are based on anticipated equipment usage and technical information available at the time these documents are prepared. As operational requirements change, and new and approved fabrication, manufacturing and overhaul techniques become available, they are not being considered and incorporated into the DMWR. Also, new improved materials and components are constantly being developed and approved. These also are not being considered as methods of reducing costs, maintaining safety, or improving inherent reliability.

It is clearly understood that the DMWR is not the vehicle for effecting engineering changes, at any level, to any item or component. However, the scrub effort is the ideal vehicle to identify those areas where changes in tasks, procedures, or materials would produce improved cost, safety, or improved reliability standards. Areas for specific consideration are those where the manufacturer has improved techniques or procedures and the depot has not followed suit. Another area is the constant flow of new or improved materials and componenets that are continually being approved for military application.

All indicators point to the DMWR scrub as being a one-time effort. There are no prepared plans for periodically reviewing the DMWR for changes that might be in order as the result of engineering decisions or modifications.

4.1.4 Conclusion and Recommendations

The DMWR scrub implemented at TARCOM has as its goal the RCM objective of scheduling only maintenance tasks essential to maintaining inherent design levels of safety and reliability. This objective will be met on the M113 if established procedures continue to be followed. It can be met when the scrub is applied to other tank and automotive products if the present procedures are carried over. However, since the M113 scrub is being accomplished under contract by Food Machinery Corporation and the TARCOM personnel most knowledgable with the effort are assigned to the M113 project office, it is probable that expertise will be lost when the DMWR scrub is applied to other tank and automotive products. To prevent this from happening, a procedures manual for conducting a DMWR scrub on other tank and automotive products should be prepared. The contents of this manual should include instructions for conducting a DMWR scrub, application of decision logic, and cost estimate sheets with instructions for their usage. Most of all, it should contain an accounting of the lessons learned on the M113 program.

Although the DMWR scrub has in the past been hampered by lack of direction, the program is on a sound footing at present. If TARCOM takes the steps necessary to transfer the expertise from one program to another, the confusion experienced on the M113 program can be avoided on other tank and automotive products.

There is no planned program for making periodic reassessment of the DMWR. Such a program should be developed and should include assessing the effect of periodic engineering decisions on depot maintenance requirements. This assessment should be made with the use of decision logic and economic effect analysis.

Maximum benefits obtainable are not being realized through the M113 DMWR scrub. Present decision logic is too narrow in scope and cannot be used effectively to identify all the possible benefits. It should be expanded to determine if there is an economical substitute action to give a lower cost, while maintaining safety and relaibility design levels. The added effort would be minimal, but the results could be significant.

In this connection TARCOM has taken the initiative to identify improved procedures and to incorporate them into the DMWR revision. Three such instances are: revising methods of packaging wheel bearings, using red dye to locate cracks in the final drive housing, and establishing a criteria for changing the front torsion rods.

4.2 ESC Elimination

4.2.1 Requirements

In June 1974, FORSCOM reported the results of a study to achieve improvement in the quality of maintenance performed on STRAF equipment. This report, "Improvement of Equipment Maintenance and Relating Reporting Procedures within FORSCOM," stressed the reliability and utility of the information reported on equipment status. The report contained numerous recommendations. Proposals eliminated from the equipment serviceability criteria (ESC) amber status and all checks that do not have a criteria for red status. As an ultimate solution simple Go/No-Go operational checks were proposed to replace present ESC requirements. These checks would incorporate the daily as well as certian other checks of items that render the equipment inoperable. In addition, a simple system check, where appropriate, was suggested. The report further recommends that these periodic operational checks be incorporated into the operator's manual. These recommendations were the source for changes to the ESC program.

The office of Deputy Chief of Staff for Logistics in a letter to DARCOM (Reference 8) directs that the Equipment Serviceability Criteria (ESC) Manual be eliminated as a separate publication. In turn, DARCOM (Reference 9) provides directions to each of the commodity dommands to revise the PMCS tables to include all necessary checks to determine Not Ready/Available status of the vehicle.

The DARCOM Message (Reference 10) established the criteria for selecting the ESC items to be integrated into the PMCS tables.

4.2.2 Response

In response to the requirement for integration of ESC into the operator manuals, TARCOM has developed a new format for PMCS tables. These revised PMCS tables are designated to replace the present tables in all operator manuals, and they will include all necessary checks to determine Not Ready/Available status of the vehicle. As the operator manuals are reviewed and revised to reduce the time required for PMCS performed before, during, and after operation, the resultant changes will be incorporated in the revised PMCS table format. At this time the ESC will also be incorporated into the PMCS tables under the column heading "For Readiness Reporting". Determination of the Not Ready/Available status during PMCS now becomes a crew function.

4.2.3 Evaluation

The incorporation of ESC into the operator manuals does not require RCM decisions in the strict sense. However, all ESC items do result in a requirement for performance of on-condition maintenance tasks (repetitive inspections or tests performed to determine the condition of the vehicle); and, only in this respect do they fall under the umbrella of RCM.

RCM decision logic is not required to select ESC items that have a criteria for Not Ready/Available status. The screening process consists of selecting those items that have a criteria for red status (items that would result in a nonoperative condition, mission abort, or unsafe condition) for transfer from the present ESC manuals to the PMCS tables in the operator manuals.

4.2.4 Conclusions and Recommendations

The use of a single question for screening and selecting the items in the ESC manual for inclusion in the PMCS tables is sufficient to obtain desired results.

Since this is a one-time effort, no recommendations will be offered.

4.3 On Condition Selection of Combat Vehicles for Depot Overhaul

4.3.1 Requirements

On condition selection of combat vehicles for depot overhaul is a technique that utilizes the results of periodic inspections performed by a qualified team to determine which vehicles are most in need of depot overhaul. Specifically, this method of selection consists of evaluating the results of the inspection of certain key items that are significant indicators of the vehicle's condition. These individual items are numerically weighed relative to importance and condition. The sum of these values is used to establish a profile index for each vehicle. Vehicles are selected for depot maintenance based on this index. Those with the worst rating are selected first.

Department of Army tasked AMC (now DARCOM) early in 1972 to develop a more realistic peacetime overhaul criteria. AVSCOM (now TSARCOM), in coordination with AMC, proposed the on condition maintenance concept for selecting Army aircraft for overhaul. The program was initiated in 1973.

In a memorandum from the Office of the Assistant Secretary of the Army to the Deputy Chief of Staff for Logistics (Reference 11), directions were given to extend the aircraft RCM logic to other Army commodities. A DA Letter (Reference 12) delegated to DARCOM the responsibility to establish procedures and methodology to achieve an on condition depot level selection criteria and to develop pilot programs on equipment representative of tracked and wheeled vehicles.

To carry out the Army's intention to make on-condition the basis of selection of equipment for depot maintenance, DARCOM instructed TARCOM to redirect an on-going study of various depot selection criteria. From this Combat Vehicle Maintenance Policy Study in which RCM principles would be incorporated, a methodology and plan would be devised for introducing on condition criteria for selection of combat vehicles for depot level overhaul.

4.3.2 Response

TARCOM, in conjunction with ARRCOM and with the support of the Army Materiel Systems Analysis Activity, Aberdeen Proving Ground, Maryland, conducted a study to define a new overhaul policy in the context of the RCM strategy. The study was conducted along the lines of the three primary areas of the overhaul selection process - technical, management, and cost.

In the technical area, the objective was to develop a technical inspection procedure through which the vehicle's need for overhaul could be determined. This included identifying certain key indicators to be scrutinized to assess the vehicle's current condition, through the use of the proper test measurement and diagnostic equipment, predict when the vehicle would require overhaul. The goal was to be able to predict at least two years in advance the time at which the vehicle would require overhaul.

In the management area, the objective was to devise a system to select those vehicles most in need of overhaul and ensure their timely arrival at the depot. Management was divided into those taks areas pertaining to the vehicle selection process and to the evaluation process. The vehicle selection process involved the assembly of data required to make a choice of vehicles to be overhauled. The evaluation process determined the routing of vehicles to the depot. The latter group focused on administrating and managing a system for producing vehicle condition evaluation and fleet profiles.

In the cost area, each step of the process was identified and isolated to perform a cost effectiveness analysis between the current overhaul selection policy and the on condition selection policy, so that the method best suited for selecting combat vehicles for overhaul could be determined.

The study was conducted in two phases. Phase I, completed in June 1977, resulted in the development of a recommended method for operation of the OCM selection system. The system was tested in Phase II, Field Validation. A total of 12 vehicles (three each of M113A1, M551, M60A1, and M109) were evaluated in a field test at Ft. Hood, with the results recorded for later scoring at TARCOM.

The study was completed September 1977. Implementation target date of the fourth quarter of the fiscal year 1978 has now slipped into fiscal year 1979.

TARCOM has prepared Standing Operating Procedure 750-5, dated 20 October 1977, to provide instructions for the operation of the special project office (located in the program management branch, DRSTA-MRM) during a pilot program for on condition selection of combat vehicle evaluation.

A pilot program has been initiated whereby all M60A1 tanks in CONUS with 5000 miles or more will be inspected by local units in accordance with instruction provided by TARCOM. The results of the vehicle condition evaluation are forwarded to TARCOM, where the vehicles needing overhaul are identified.

The pilot program inspection and vehicle selection conducted through March 1978 showed the following findings:

1 A total of 60 vehicles with an excess of 6000 miles were identified for evaluation and 13 were selected for overhaul; 44 vehicles with over 5000 miles were identified for evaluation, and 15 were selected for overhaul.

2 A total 28 vehicles with less than 5000 miles were submitted by their owners for evaluation, and 14 were selected for overhaul.

3 A total of 132 vehicles were subjected to the vehicle condition evaluation, and 42 (31.9 percent) were selected for overhaul.

As of 26 July 1978, 171 vehicle condition evaluations have been performed, resulting in the selection of 48 tanks for overhaul.

4.3.3 Evaluation

TARCOM has completed and submitted to DARCOM its study introducing on condition criteria for selecting vehicles for depot overhaul. The study, completed in September 1977, is now awaiting approval before being fully implemented. It is understood that both U.S. Army Europe and FORSCOM have some objection to TARCOM's recommended plan. These objections have resulted in delay of the approval.

The Combat Vehicle Maintenance Study Report is concerned mainly with presenting the methodology used in examining the problem of achieving on condition selection of vehicles for overhaul. In some instances, it

presents a description of procedures to be used in the on-condition selection process. The report highlights many problems expected to arise with the implementation of the on condition vehicle selection, but it fails to identify remedies for solving several major problems.

Data collection and analysis are of paramount importance to any RCM program as is the case with on condition selection of vehicles for overhaul. Information such as RAM data for end items, components, and parts that are key drivers in determining overhaul requirements, life cycle cost data, and cost of field maintenance, does not exist or is so fragmented that its value is suspect. Without accurate and complete data of this type available, it will be difficult to evaluate the program and correct any imbalances that occur after program implementation.

Methods are not addressed for establishing the critical threshold - the point at which the numerical value or combination of numerical values indicate that the vehicle is a candidate for depot maintenance. The analysis and decision process for screening the candidate vehicles is not defined.

There is no indication as to how catastrophic failures are to be handled, i.e., whether they are to be considered under the on condition selection program or if the determination of the maintenance requirements for this type of failure is to be completely divorced from this program.

Once the on condition selection program has been implemented, there should be a period during which the results of the vehicle condition evaluation are compared to the findings of the preshop inspection. This should be done to determine that the evaluation criteria are satisfactory for determining the overall vehicle condition. Evaluation criteria that do not completely meet expectations they should be identified.

The study fails to establish the method for grading key indicators numerically, based on their condition and importance to the overall condition of the vehicle. Key indicators and numerical values available for grading each indicator will no doubt be unique for each type of vehicle.

4.3.4 Conclusions and Recommendations

TARCOM has, through the completion of the Combat Vehicle Maintenance Policy Study, developed and recommended a methodology and plan for utilizing on condition criteria for selecting combat vehicles for depot overhaul. However, TARCOMs recommended program is weak in the incorporation of RCM principles in both the development and implementation of its recommended program. The basic on condition selection philosophy recommended by TARCOM is workable, as proven by the results of the pilot (M-60) program. However, since the pilot program deviated from the plan in the operational mechanics (inspection was performed by local units rather than TARCOM personnel), it remains to be proven that the recommended program can be effectively implemented on a worldwide basis, at the forecasted rate and manpower and within the dollar value indicated in the report.

It is recommended that the decision logic shown in Figure III-4 be incorporated into the analysis and decision process to determine whether the vehicle is qualified for overhaul. This logic diagram has been developed in consonance with the RCM philosophy to provide a method of determining vehicle disposition. The questions are designed to be used in determining which of the following four possible dispositions is best for the vehicle under evaluation:

1 Depot overhaul not required

2 Item beyond economical repair

3 Overhaul deferred to a later date

4 Immediate depot overhaul indicated.

The use of the decision logic will provide a means for establishing uniformity in the decision-making process among a number of different personnel who will be rendering the decisions. See Appendix B for additional detail.

Prior to full scale immplementation of an on-condition vehicle selection program, the data requirement should be identified and collection methods established to obtain the RAM and real cost data necessary to evaluate the effectiveness of the program and to correct imbalances.

The question of what action to take in the case of catastrophic failure or accident damage should be addressed. If this type of situation falls outside of the parameters of the on-condition vehicle selection program, it should be so stated.

Two functions that should be addressed are 1) the developing of methods for establishing the numerical values for each key indicator, and 2) the establishing of the critical threshold as the point at which the vehicle becomes a candidate for overhaul. The application of decision logic could be used to advantage in creating a uniform procedure for establishing these two critical program elements.

A means should be established for comparing results of the preshop analysis with the condition indicated in the vehicle condition evaluation report. This should be done early in the implementation of the on condition vehicle selection program for each vehicle. Once the validity of the vehicle condition evaluation criteria is established, this comparison would no longer be routinely required. In fact, it may be possible to delete the preshop analysis, except on a random basis to serve to monitor the effectiveness of the on condition vehicle inspections.

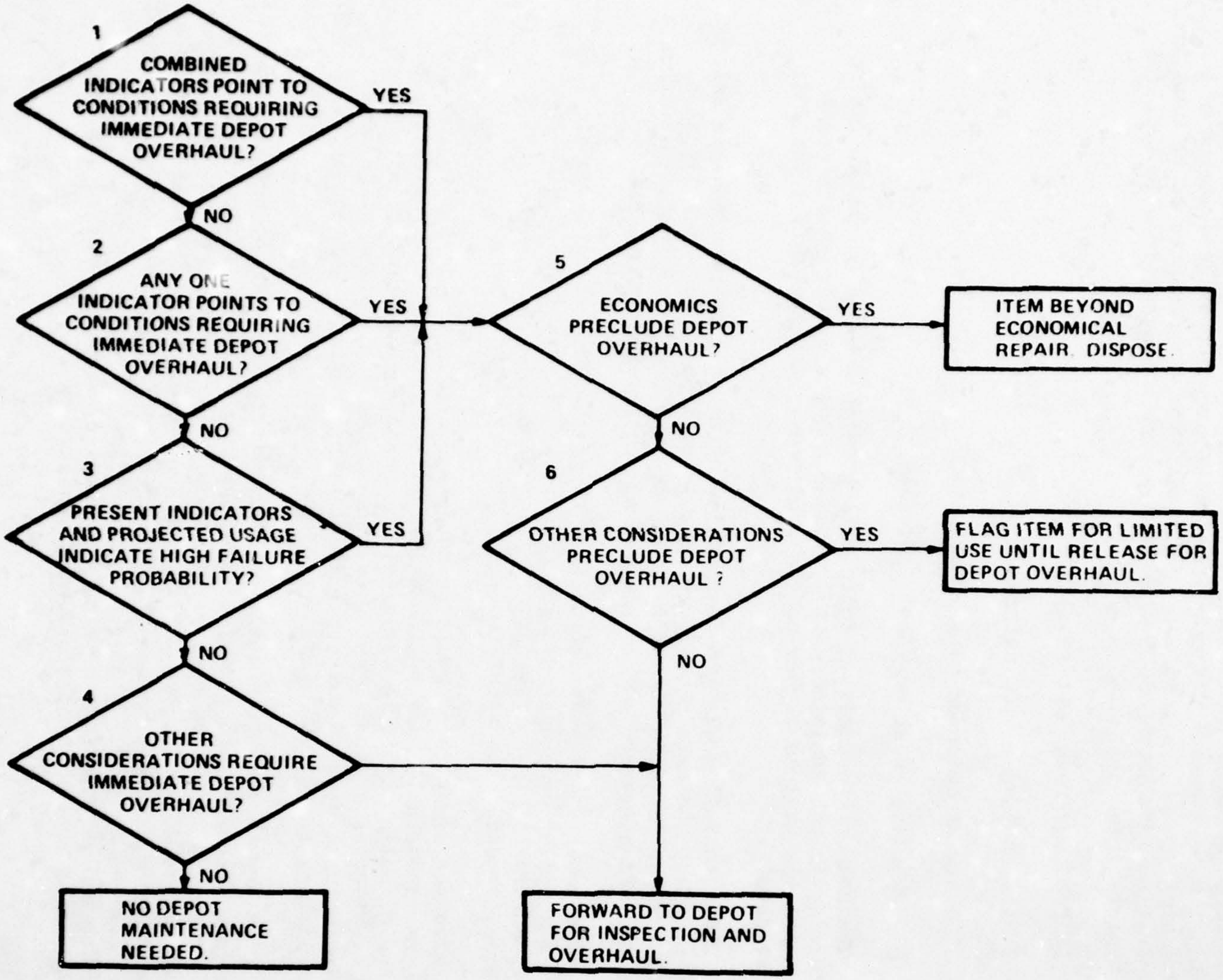


Figure III-4. Overhaul Selection Logic

4.4 Oil Analysis

4.4.1 Requirements

Oil Analysis is a series of tests that provides an indication of the physical condition of engines or engine parts, gear boxes, and transmissions. The concentration of contaminates such as wear metals, water, rust particles, chemicals, and oil dilution are some of the problems that the analysis uncovers.

The Army became involved in the Oil Analysis program in 1961, when aircraft were placed under the program in an effort to enhance flight safety.

Based on the results of a test program conducted at Ft. Hood, Texas, Headquarters, III Corps, in a letter to FORSCOM (Reference 13) recommended that the Oil Analysis program be extended to nonaeronautical equipment. FORSCOM endorsed the III Corps position and forwarded a recomendation to DA (Reference 14) that this extension be approved. Department of Army, in a second endorsement (Reference 15), approved the III Corps recommendation and directed its implementation.

4.4.2 Response

Some 26,000 vehicles of all types are presently under the Oil Analysis program. Each of the nine laboratories is processing approximately 5000 oil samples per month. In 1977 seven of the laboratories processed in excess of 421,000 oil samples.

The Oil Analysis program was implemented on the M113 family of vehicles during fiscal year 1976.

Generators of 15 KW capacity and larger will be included in the program in the coming year if laboratory capability permits. Wheeled vehicles having a capacity of 2.5 tons or more are being considered for inclusion in the program in 1980.

Revision of Field Procedure Guide, TB43-0210, that contains feedback requirements for all activities is being prepared. Distribution is expected prior to the end of fourth quarter fiscal year 1978.

4.4.3 Evaluation

Administration of the program is assigned to the Army DARCOM Material Readiness Support Activity, Lexington, Kentucky. The program has become a part of a tri-service operation.

Oil Analysis cannot be considered a RCM program per se. However, it results in an on condition maintenance action which can be considered to fall under the RCM umbrella.

When oil sample tests indicate a maintenance action is required. The evaluator makes recommendations to the field unit. Results of the tear-down analysis are returned to MRSA and the evaluator so that the accuracy of the evaluator's prognosis can be determined. During Fy77 the laboratories made 310 recommendations on non-aeronautical equipment. To date feedback has been received from 35 percent of the recommendations. This situation cannot provide a clear picture or the effectiveness of the program.

4.4.4 Conclusions and Recommendations

The Oil Analysis program is working well as far as obtaining and testing samples. However, the program breaks down in that Section V of technical bulletin TB 43-0210 is not being adhered to fully. Noncompliance with Section V, Feedback Data, exists in 65 percent of the cases where maintenance actions were recommended by the laboratory.

If this program is to be a truly usable diagnostic tool, feeback from all maintenance facilities is essential. It is needed to refine the evaluation criteria and process for increased accuracy of laboratory predictions and for its potential to recommend design changes in those equipments that show rapid wear or have an abnormal failure rate.

It is doubtful that publishing a field procedures guide with its revised reporting forms will result in an improvement in the feedback situation. What must be provided is strong command emphasis in a form the maintenance organization cannot ignore.

4.5 Reduced PCMS

4.5.1 Requirements

PMCS provide the means of ensuring that the equipment is operating at maximum efficiency and that defects are found and corrected before serious damage occurs. In general, PMCS are on-condition maintenance tasks performed on a before, during, and after operations on weekly and monthly schedule.

The requirement to review organizational scheduled maintenance requirements and reduce or eliminate those checks and services having marginal value was established by the Office of the Deputy Chief of Staff for Logistics (Reference 16). DARCOM in turn directed that a one-year study be undertaken, with each commodity command selecting its own approach. This was done through DARCOM Letter (Reference 17). In February 1976, DARCOM revised the guidance previously given the commodity commands (Reference 18). Additional guidance for revising the operations manuals was contained in DA letter (Reference 8). This included defining the inspection or test frequency as daily, weekly, or monthly combat operating

checks (replacing ESC) and monthly checks to fulfill the preventive maintenance requirement. DARCOM in their letter (Reference 9) directed the implementation of the DA guideline contained in Reference 8.

The final report of Project LEAP, Issue 127 (Reference 19) recommends that project LEAP be terminated and that the review and reduction of PMCS be continued as part of RCM. DARCOM in their letter (Reference 20) directed the transition in the review and revision of PMCS from Project LEAP to RCM. This direction was reiterated in DARCOM message (Reference 10).

4.5.2 Response

Review and reduction of PMCS is being accomplished in two stages resulting in generation of two types of revised operator manuals, pre-RCM and post-RCM. Reduction in PMCS was initiated under Project LEAP, Issue 127, which included a test review and reduction of PMCS in the -10 and -20 operators manuals on the M60A, M113A1, and M34A2.

LEAP was closed out and reduction of PMCS is continuing under RCM. The present schedule calls for a review and reduction of PMCS on all maintenance-significant equipment by fiscal year 1979.

The initial pre-RCM screening of the -10 and -20 operator manuals was accomplished without the application of decision logic. Decision logic was applied when RCM objectives were added to the screening process. TARCOM developed its own decision logic for this purpose and established an internal review board with responsibility to review the revised manuals and pass judgement on the adequacy of the revision. This board also provides instructions to the personnel who have the responsibility for review and revision of the PMCS. TARCOM has developed a plan, Reliability Centered Maintenance Checks and Services, to supplement DARCOM's RCM Implementation Plan of December 1976 (Reference 21).

ESC incorporation has been combined with the review and revision of PMCS to keep the revision of the operator manuals to a minimum.

4.5.3 Evaluation

TARCOM is proceeding in the review and revision of PMCS contents of the operator manuals in accordance with instructions and guidelines provided. However, these instructions have often been incomplete and confusing, requiring several revisions.

The revision of PMCS was started early in 1977. As of April 1978 the guide to the Application of Reliability Centered Maintenance to Preventive Maintenance Checks and Services Requirements for Non-Aeronautical Fielded System, DA Pamphlet 750-XX, has not been published. The schedule for publishing this document is August 1978.

The revision of PMCS was started early in 1977. As of April 1978 the guide to the Application of Reliability Centered Maintenance to Preventive Maintenance Checks and Services Requirements for Non-Aeronautical Fielded System, DA Pamphlet 750-XX, has not been published. The schedule for publishing this document is August 1978.

Although TARCOM published a supplement to DARCOM's implementation plan, providing guidelines for applying RCM to the PMCS review, it was not provided to all personnel conducting the PMCS screening. Some were given only verbal instructions on how to review the PMCS. This can result in inconsistency in the program.

General Gibson, in his 5 February 1976 letter, recommended that the following actions be accomplished as a minimum in reviewing and revising the PMCS under Project LEAP:

1 Examine the effects of reductions of scheduled maintenance actions on unscheduled maintenance

2 Examine the possibility of unscheduled but predicted maintenance actions, to permit reductions in scheduled checks

3 Insure that scheduled checks not contributing to operational readiness (OR) are deleted

4 Increase the number of test items included in the evaluation

5 Investigate design changes as a means for reducing maintenance requirements.

Items 2, 4, and 5 have been completely overlooked in the instructions and guidelines. Also, the decision logic does not address these items. The result is that there has been no formal evaluation along these lines.

A sample of the PMCS task reduction TARCOM is experiencing through the PMCS review and revision program is shown in Table III-1. The estimated time savings resulting from the PMCS revision of TM-9-2320-233-10 is shown in Table III-2. Using the time savings indicated and assuming 20 days of operations per month, the net savings would be 41 hours (average 123 minutes per day per vehicle) for each M520, M559, M553, and M577 in each monthly operation cycle.

This would indicate that PMCS would now require an average of 11 minutes per day. Before revision, it required an average of 134 minutes per day. At first glance it would appear that a large cost savings can be realized from this revision effort. However, when considering that the bulk of the maintenance is accomplished by the operator personnel with assistance by the organizational maintenance personnel, the cost savings will be minimized. The operator personnel cannot be decreased and before the organizational maintenance personnel can be decreased the MOS structure must be given critical analysis.

TABLE III-1 PMCS Task Reduction

Technical Manual Number	Before Review B	D	A	W	M	TOTAL	After Review B	D	A	W	M	TOTAL
TM9-2320-233-10	72	12	14	40	14	152	26	15	2	19	21	83
TM9-2350-247-10	19	4	7	–	15	45	16	5	6	–	13	40
TM9-2330-273-10	26	15	1	25	11	78	16	15	1	26	7	65
TM9-2320-218-10	40	9	24	–	–	73	16	10	–	2	17	45
TM9-2350-230-10	146	37	77	–	–	260	114	17	61	–	4	196

TABLE III-2 Operator PMCS Time Requirements

System/TM	Type	Before Review No. Checks	Before Review Time Minutes	After Review No Checks	After Review Time Minutes	Savings Per Vehicle Minutes
TM9-2320-233-10 Goer Vehicle System M520, M559, M553, M877	Before	72	97	26	6	91
	During	12	--	15	--	--
	After	14	24	2	1	23
	Weekly	40	62	19	15	47
	Monthly	14	17	21	26	-9

4.5.4 Conclusions and Recommendations

To date, TARCOM's performance in reviewing and revising PMCS has been responsive to the instructions and guidelines provided. The PMCS review and revision could have been much more efficient had the program planning at higher headquarters been orderly and systematic.

In August 1974 the Army Chief of Staff tasked the Army to identify the problem - saving of men, money, and material. In April 1975 DA DCSLOG tasked DARCOM to conduct a review of organizational scheduled maintenance requirements and reduce or eliminate those services having marginal value. DARCOM in turn passed the task to the commodity commands in August, 1975. Revised guidance was given the commodity commands in February, 1976. A DA pamphlet providing guidance for use of RCM in revising PMS, however, is still in draft form and has not yet been published.

4.6 RISE

The Reliability Improvement of Selected Equipment (RISE) program has as its objective reliability, availability, and maintainability improvement through equipment redesign to reduce life cycle maintenance support costs.

No specific RISE actions are being implemented at this time on any tank or automotive product. As the result of this inactivity no active survey was made of the RISE program.

TARCOM has published a statement in it's fact sheet dated April 1977 that the principles of RCM will be considered in future applications of RISE. However, specific steps to incorporate RCM principles into the RISE program have not yet been taken. It is not likely that any steps will be taken prior to the application of RISE to some item of equipment or system.

If RISE is indeed a viable candidate for future application, AMC regulation (Reference 22) should be immediately revised to include the application of the RCM principles.

5.0 OVERALL ASSESSMENT AND RECOMMENDATIONS

TARCOM personnel were both friendly and cooperative throughout the on-site survey and in answering follow-up inquiries during the period this report was in preparation.

In general, TARCOM has been responsive to RCM direction from higher headquarters. RCM, as implemented at TARCOM, fulfills the requirements established by DA and DARCOM, with the major effort concentrated in revision of the Depot Maintenance Work Requirement (DMWR) and review and revision of Preventive Maintenance Checks and Services (PMCS) contained in the -10 and -20 operator manuals. Other programs that contain elements of RCM implementation are ESC Elimination, On Condition Depot Maintenance Selection, and Oil Analysis.

While each of the above programs contains some element of RCM, none employs the application of the RCM principle of engineering analysis. In fact, there has been no attempt to develop a comprehensive RCM program for any tank or automotive product. Such a program applies decision logic and engineering analysis at the system and component level to 1) identify the systems and their significant items, 2) identify functions, failure modes, and failure effects, 3) define the scheduled maintenance task that has potential effectiveness relative to the control of operational reliability and safety, and 4) assess the desirability of implementing these tasks.

Without at least one comprehensive RCM program or at least a concentrated RCM effort on some major components of a tank or automotive product, no way is provided to gauge the benefits that may accrue from such an effort or to judge whether a comprehensive RCM effort would produce additional cost effective results when compared to the present level of RCM implementation.

A comprehensive RCM program should be developed for at least one tank or automotive product, and a comparison made with the results of the present level of RCM implementation. If time or money will not permit the development of a full-blown RCM program, a comprehensive program should be developed for some major components of a tank or automotive product, and the results compared with the present level of RCM implementation for those components.

Higher headquarters has tended to direct a start in a specific effort without providing fully documented requirements. Therefore they have failed to provide explicit instructions. A case in point is the DMWR scrub. TARCOM was tasked to conduct the DMWR scrubs in February but what was required and desired was not clarified until a meeting in September. Another example is the PMCS review and revision. The program has been implemented for nearly three years and thus far the DA pamphlet providing guidance has not been published.

All future RCM programs should be developed logically and systematically, with each step in process completed to the point that the remaining portion will not effect the succeeding steps. For example, DA and DARCOM must identify the task or problem, establish the requirements necessary to develop the task or solution, prepare instructions and guidelines for implementing the task or solution, assign an organization with the responsibility of implementing the task or solution (and provide them with instruction and guidelines immediately), obtain feedback, and monitor results. Unless a program is developed systematically in sequence, the results will always be confusion and wasted time.

The present approach to the DMWR scrub and PMCS review is to revise the content of the existing publications, generally by deleting or revising those items found to be excessive to the requirements. Little or no attempt is made to investigate design changes or to consider improved materials and procedures as a means of reducing maintenance. Neither has any consideration been given to revising the number of test points to improve evaluation of the equipment's capability to meet its requirements. There has not been any evaluation which considers the possibility that unscheduled, but predictable maintenance, can provide a means of decreasing schedule maintenance.

A concerted effort appears to have been made to reduce the decision logic used in the DMWR scrub and PMCS review to the minimum number of questions possible. In doing this, a number of possibilities that would result in reduced maintenance and costs are being overlooked.

On future RCM programs it would be beneficial to apply a broad approach by examining all possibilities, as time and money will allow, to reduce the maintenance burden. With the present narrow point of view only a portion of the potential savings is realized. The RCM decision logic should be tailored to accomodate this broad view approach.

Many conversations with TARCOM personnel revealed a great deal of confusion regarding terms used in conjuction with RCM. Specifically confusing was the term "on-condition," a term used as a RCM maintenance classification, that also defines the program that selects vehicles for overhaul. Also, the two terms on-condition and condition monitoring sound alike, and this contributes to the confusion.

The terms and phases used in conjunction with RCM should be examined. Those that have a double meaning or are confusing by character or relationship should be dropped from future programs.

REFERENCES

1. DA Contract DAAG-39-77-C-0169, 23 August 1977.

2. Military Specification MIL-M-63041B, 16 August 1977.

3. DA Message DA 04 2225Z, 4 February 1977 SAB.

4. DARCOM Message R22 2209Z, February 1977.

5. Memo for Record - DRCPM-M113L.

6. DA Contract DAAE-07-76-C-0257.

7. U.S. Army Tank Automotive Command, Engineering Work Directive, WD No. 070-807-100, Rev. No. 2.

8. DA Letter DALO-SMM-F, 12 February 1976.

9. DARCOM Letter DRCMM-MP, 2 June 1976.

10. DARCOM TWX 03 2030Z, March 1978.

11. Memorandum for Deputy Chief of Staff for Logistics from Office of the Assistant Secretary of Army, 15 June 1976.

12 DA Letter, HQDA Letter 750-16-3, 23 September 1976.

13. III Corps Letter AFZF-GD-M, 17 December 1974.

14. FORSCOM Letter AFLG-EQ, 13 January 1975 (First Endorsement to Reference 14).

15. DA Letter DALO-SSM-E, 5 February 1975 (Second Endorsement to Reference 14).

16. DA Letter DALO-PLD, 21 April 1975.

17. DARCOM Letter AMCMA-SE, 13 August 1975.

18. DARCOM Letter DRCMA-SE, 5 February 1976.

19. Project LEAP, Issue 127, Final Report, 1 January 1977.

20. DARCOM Letter DRCMM-MS, 1 October 1976.

21. Implementation Plan - RCM Application to PMCS, Reference DF, DRSTA-M, 23 June 1977.

22. AMC Regulation 702-15.

EXHIBIT IV

CERCOM/ERADCOM RCM SURVEY REPORT

SUMMARY

The intent of Part 1 of this survey was to review the application of Reliability Centered Maintenance (RCM) principles to the AN/VRC-12 radio set. An on-site review in support of this objective was held on 20 March through 24 March 1978 at the U.S. Army Communications and Electronics Materiel Readiness Command (CERCOM), Fort Monmouth, New Jersey. While on-site, Part 2 of this survey, an evaluation of the RCM effort on the AN/TPQ-37 radar set (Artillery Firefinder), the Electronics Research and Development Command (ERADCOM) developmental system RCM candidate, was also undertaken.

Part 1: CERCOM SURVEY

No formal program for implementation of RCM on the AN/VRC-12 radio set was established by CERCOM. However, they did engage in RCM activities related specifically to the AN/VRC-12 radio set and, in general, to all of the command's maintenance significant systems. The following activities were analyzed:

1 Development of RCM understanding and expertise

2 AN/VRC-12 preventive maintenance checks and services (PMCS) revision effort, including integration of equipment serviceability criteria (ESC)

3 Development of a Depot Maintenance Work Requirement (DMWR) and depot work policy review program plan for the AN/VRC-12 radio set.

As a result of the analysis, the following recommendations were made:

1 Assistance must be provided to CERCOM in identifying techniques applicable to RCM implementation on electronics equipment.

2 Resources must be identified or developed to provide the command with the capability for performing a failure mode effects and criticality analysis (FMECA) or equivalent.

3 Since no RCM logic was used in the revision of the AN/VRC-12 operator PMCS, the effort should be redone using the guidelines set forth in the draft Department of the Army (DA) pamphlet, "Guide to RCM for Fielded Equipment."

4 The plan for review of DMWRs and depot work policies should be completed and implemented as soon as practical.

Part 2: ERADCOM SURVEY

The AN/TPQ-37 radar set was erroneously identified as a developmental system candidate for RCM implementation. ERADCOM indicated the system is in the low rate initial production phase. RCM activities to date consist of issuance of implementation guidelines to the system contractor. Thus far no indication of RCM accomplishments has been provided.

Based on a review of the ERADCOM RCM related actions and the integrated logistics support requirements for the AN/TPQ-37 system, the following recommendations were made:

1 RCM should be implemented on the AN/TPQ-37 radar set as a fielded system.

2 The Army should identify a developmental system candidate for RCM implementation.

3 Alternate guidelines to those specified in Appendix C to AMCP 750-16, "DARCOM Guide to Logistics Support Analysis", should be provided for RCM application when logistics support analysis and FMECA are not included as specification requirements for developmental systems.

EXHIBIT IV

CERCOM/ERADCOM RCM SURVEY REPORT

1.0 CERCOM SURVEY

1.1 BACKGROUND

1.1.1 Purpose of Survey

The evaluation of the application of Reliability Centered Maintenance (RCM) principles to the AN/VRC-12 radio set was the purpose of the survey.

1.1.2 Organization Surveyed

U.S. Army Communications and Electronics Materiel Readiness Command
(CERCOM)
Fort Monmouth, New Jersey 07703

1.1.3 Date of Survey

1 Initial (via telecon) - 24 January 1978

2 On-site - 20 March through 24 March 1978

3 Follow-up (via telecon) - 3 April through 5 May 1978

1.1.4 Persons Contacted

CERCOM Maintenance Directorate

Mr. Bruce Ballance
Engineer, Communications Maintenance Engineering Division

Mr. Vincent Calfapietra
Chief, Maintenance Engineering Branch
Plans, Programs, Engineering Division

Mr. John Juditz
Chief, Technical Publications Division

Mr. Greg Lentzakis
Writer, Communications Publications Branch

Mr. A. S. Lusey
Chief, Communcations Publications Branch

Mr. Charles Seal
RCM Action Officer, Maintenance Engineering Branch
Plans, Programs, Engineering Division

1.2 OBJECTIVES AND SCOPE

The U.S. Army Communications and Electronics Materiel Readiness Command (CERCOM) survey was conducted in compliance with contract DAAG-39-77-C-0169, Assessment of the U.S. Army Implementation of Reliability Centered Maintenance (RCM) (Reference 1), which was let to the Martin Marietta Corporation in Orlando, Florida. The objective of this survey was to evaluate the command's implementation of RCM on the AN/VRC-12 radio set. Pursuant to this evaluation effort, RCM-related activities on other systems managed by CERCOM were identified. These additional activities are highlighted in this report only to the extent necessary to accurately reflect CERCOM's total RCM program accomplishment. A companion effort to the CERCOM survey was a review of the Electronics Research and Development Command (ERADCOM) implementation of RCM on the developmental assessment candidate system, AN/TPQ-37 radar set (Artillery Firefinder). The ERADCOM survey report is included as Part 2.0 of this exhibit.

1.2.1 Survey Approach

The CERCOM survey was conducted in three phases - initial contact by telephone, 5-day, on-site survey at Fort Monmouth, and follow-up by telephone. The initial contact was made for the following reasons:

1 Establish a point of contact between the Martin Marietta Corporation and CERCOM

2 Make CERCOM aware of Martin Marietta's role within the scope of the RCM assessment contract

3 Obtain an overview of the RCM activities within the command

4 Establish a firm time schedule for the on-site survey.

The on-site survey effort included the following:

1 Interviews with personnel within the Maintenance Directorate to identify all the elements of the RCM program for the AN/VRC-12 radio set, problem areas encountered in program implementation, and achieved results.

2 Research of the RCM data files to identify all significant correspondence, directives, and guidance relevant to the CERCOM RCM activity.

The follow-up phase of the survey provided a means for clarifying both the information discussed during the personal interviews and the data accumulated during the on-site visit. It also identified developments occurring between the time of the on-site visit and the preparation of this report.

1.2.2 On-Site Visit

The reception received at CERCOM headquarters was very cordial, and the RCM action officer, Mr. Charles Seal, was extremely cooperative for the duration of the survey. The working groups interviewed within the directorate, publications and engineering personnel, were generally aware of the basic concept of RCM and willingly participated in the survey activities.

The dialogue exchange with Mr. Seal was invigorating and informative. The initial impression of the CERCOM outlook on RCM was positive. They appear to have an understanding and acceptance of the RCM philosophy. CERCOM's interpretation of RCM is that "RCM is the philosophy for developing the optimum preventive maintenance (PM) program in terms of efficiency and cost. The technique is to screen out, in a logical process, those PM tasks which will not contribute to the prevention of deterioration of an equipment's inherent level of reliability and operating safety. RCM is implemented by using a decision logic technique which has been incorporated into the logistics support analysis process."

1.2.3 General Problems

Implementation of RCM on the AN/VRC-12 radio set does not include at this time a comprehensive or formal RCM program. Before CERCOM can entertain any thoughts for planning a complete RCM effort, certain basic needs that are common to all commodity commands must be fulfilled. There is a requirement for formal guidance to be provided from higher command levels for the application of RCM. This guidance must include at a minimum, the logic necessary for making RCM decisions along with complete instructions for implementation. A second, and equally pressing, need is for the command to develop the capability for performing a failure mode effects and criticality analysis (FMECA). A FMECA is one of the primary input data requirements for a RCM program, and a lack of this capability will severely hamper any formal RCM implementation effort. The lack of the FMECA capability within the directorate became evident when they were asked to perform this type of analysis on a selected number of maintenance significant items (MSIs) on the AN/VRC-12. The directorate response was that they had neither the required data nor the expertise to fulfill the request.

1.3 RCM APPLICATION

Although no comprehensive or full scale program has been implemented on the AN/VRC-12 radio set, there has been significant RCM-related activity within the command including:

1 The development of a RCM understanding and implementation capability

2 The preventive maintenance checks and services (PMCS) revison and equipment serviceability critera (ESC) integration on the AN/VRC-12 radio set and other systems under management control of the command

3 The preliminary planning for a program to scrub the AN/VRC-12 Depot Maintenance Work Requirement (DMWR) and review the depot work policies.

These activities are described and discussed in the following paragraphs.

1.4 RCM-RELATED ACTIVITIES

1.4.1 Development of RCM Understanding and Expertise

The CERCOM Maintenance Directorate has displayed a very positive attitude toward promotion of the RCM philosophy and has attempted to develop the capability for its implementation on the systems it manages. This attitude was readily discernible from the personal interviews conducted and the data extracted from the RCM data files during the on-site survey.

Col. A. Suso, the Director of Maintenance, in his internal correspondence of 30 September 1976 (Reference 2) to all directorate division chiefs, established the Plans, Programs and Engineering (PPE) Division as the focal point for RCM. Mr. Charles Seal was named the RCM Action Officer. He tasked the PPE Division with development, implementation, and monitoring of the CERCOM RCM program. Col. Suso directed his division chiefs to coordinate any actions, recommendations, and other related activities pertaining to RCM with the focal point.

Subsequent actions by personnel from the PPE Division provide evidence of the promotion of and participation in the RCM program within the command. These activities include the following:

1 A literature search has been conducted to uncover available documentation related to RCM. Some of the areas probed include the U.S. Navy Ship Systems Maintenance Monitoring and Support Office, Naval Air Systems Command, Office of the Air Force Deputy Chief of Staff for Systems and Logistics, Air Transport Association of America, United Airlines, and the Office of the Assistant Secretary of Defense.

2 RCM information briefings of the division chiefs have been held within the directorate by Mr. Seal.

3 Development of the "CERCOM RCM Implementation Guide" (Reference 3) has been completed.

4 Comments to the U.S. Army Materiel Readiness Support Activity on the then proposed Appendix C to AMCP 750-16 (DARCOM Guide to LSA) entitled "Analysis Guidelines for Determination of the Maintenance Plan Using the Principles of RCM" have been submitted. A suggestion to incorporate an example of RCM application to an electronics system was included in the comments.

5 Timely and thorough responses to RCM-related requests from higher level commands have been submitted and include estimates of in-house and contractor RCM manpower and funding requirements, development of schedules on the command's materiel readiness reportable systems, results of RCM activities, and participation in the development of RCM application guidelines.

The command is involved in the management of a product line that perhaps, in comparison to other commodity commands, possesses a limited potential for benefits to be derived from RCM application. This notion is based on the premise that electronic components fail randomly since they display a constant failure rate characteristic over much of their expected life, and the time from onset to failure to actual failure (T_{OS}) is either very short or not economically discernible. In view of these circumstances, assistance must be provided to this command, supplementary to the issuance of RCM application guidelines, to identify possible areas or methods for RCM implementation.

The U.S. Navy application, some years ago, of ring time measurement to their shipboard radar systems or similar techniques might prove beneficial to the command. Ring time measurement, usually performed on a daily basis, consisted of application of the radar transmitter pulse into its receiver through a power limiting device and measurement of the response on an A scope indicator in terms of yards of range. The measurement was an evaluation of the overall system operation including transmiter output and receiver sensitivity. A decrease in measured ring time was an indication of deterioration of system performance and usually was manifested in reduced operating range. Subsequent diagnostic checks of the transmitter and receiver normally resulted in identification of a deteriorated or failed component, e.g., an intermediate frequency (IF) amplifier tube with reduced transconductance. Replacement of the component would restore the ring time to its inherent level accompanied with a corresponding increase in effective system operation.

A procedure used by a large commercial computer manufacturer on one of their digital computer systems was a marginal checking technique designed primarily to eliminate intermittent system failures. The computer configuration included a large number of blocking oscillators (BOs) that were controlled by a bias supply of negative 12 volts dc. During PM periods, certain diagnostic routines would be run with the bias supply being decreased (greater negative value) until a failure was introduced. The setting of the bias level was compared to the previous established inherent bias level. If the failure was introduced at a lesser level than the inherent value, e.g., negative 13 volts as compared to an inherent level of perhaps negative 15 volts, this would be an indication of a deteriorating BO circuit. Identification and replacement of the appropriate component would restore the inherent bias level characteristic of the system.

The ring time measurement and marginal checking are examples of techniques that can be applied to detect deteriorated or failed electronic components. Similar approaches on a system or end item basis may prove beneficial to the command in identifying application techniques for RCM on electronic equipment.

1.4.2 PMCS Revision and ESC Integration

The PMCS revision effort, including the integration of ESC, was conducted on the AN/VRC-12 radio set and other command-managed equipment as a result of the 2 June 1976 letter (Reference 4) from DARCOM to the commodity commands. The letter advised the commands of the DA directive to revise PMCS and eliminate ESC manuals as separate publications. A subsequent message from DARCOM on 1 October 1976 (Reference 5) requested a schedule to be forwarded to the Maintenance Management Center for application of RCM to PMCS and the ESC integration on all active maintenace significant systems. CERCOM responded with correspondence to the Maintenance Management Center on 8 November 1976 (Reference 6) which reflected the schedule for PMCS revision on their 53 materiel readiness reportable systems, of which 12 were designated as their most maintenance significant items. The AN/VRC-12 was included as one of those 12 systems, listed in Table IV-1. This, in essence, was the preliminary activity leading to the CERCOM-PMCS revision program in general and the AN/VRC-12 radio set specifically.

Table IV-1. CERCOM - Most Maintenance Significant items

Equipment Type Number	Nomenclature
AN/MTC-1	Central office telephone
AN/TSC-76	Communications center patching
AN/VSC-2	Radio teletype set
AN/VSC-3	Radio teletype set
AN/GRC-122	Radio teletype set
AN/TRC-80	Radio set
AN/GRC-106	Radio set
AN/PRC-77	Radio set
AN/MPG-4	Radar set
AN/PPS-5	Radar set
AN/TRC-145	Radio set
AN/VRC-12	Radio set

Thus far PMCS tables for 12 equipments, including the AN/VRC-12 radio set, have been revised. This total effort was reviewed by the DARCOM Materiel Management/Command Logistics Review Team (CLRT) during a visit to CERCOM headquarters from 30 January to 3 February 1978. The CLRT concluded that the revised PMCS are inconsistent with RCM principles. As a result of this evaluation, the CERCOM intent is to redo these PMCS tables utilizing the draft DA pamphlet "Guide to RCM for Fielded Equipment", dated April 1978. Consistent with this plan of action, CERCOM requested and received a waiver from DARCOM for preparing a RCM technical manual accomplishment report on the subject 12 equipments until the PMCS tables are redone.

The effort reviewed by the CLRT includes the revision of the PMCS tables in TM 11-5820-401-12, "Operator's and Organizational Maintenance Manual" for radio set AN/VRC-12 (Reference 7). The revised tables were then incorporated into TM 11-5820-401-10-1, "Operator's Manual" for radio set AN/VRC-12 (used without intercom systems) (Reference 8) and TM 11-5820-401-10-2, "Operator's Manual," for radio set AN/VRC-12 (used with intercom systems) (Reference 9). Revised tables to be included in TM 5820-401-10-3, "Operator's Manual," for radio set AN/VRC-12 (used in the retransmission and radio/wire integration modes), and TM 11-5820-401-20, "Organizational Maintenance Manual," for radio set AN/VRC-12 are also planned.

The revised tables for the 10-1 and 10-2 Operator's Manuals are identical except for the inclusion of the intercom equipment in the 10-2 manual. Due to this similarity, further reference will only be made to the 10-1 revised PMCS table which is incorporated in Reference 8. The PMCS for the 10-1 manual was started in April 1977 and completed in May 1977. The original intent was to have the Communications Maintenance Engineering (CME) Division personnel develop the revised PMCS and for the technical writers in the Communications Publications Branch to provide the formatting effort. Due to higher priority commitments, the CME Division did not produce the new PMCS. Consequently the PMCS were developed by the technical writers, utilizing intuitive judgment and recommendations resulting from the red team survey of the AN/VRC-12 radio set as the revision criteria. The red condition criteria in the ESC manuals was integrated into the tables by the addition of notes in the equipment not ready/ available column for the applicable item numbers in the table.

A comparison analysis of the annual manhour requirement to perform the old and new PMCS for the AN/VRC-12 was made by the command. The results of that analysis are shown in Table IV-2. As indicated, the manpower expenditure varies directly with increased equipment operating time. A graphic display of the comparison data is exhibited in Figure IV-1 and shows a five day/week operational scenario resulting in an approximate 7 percent decrease in annual manhours required when using the new PMCS (52 hours versus 56 hours).

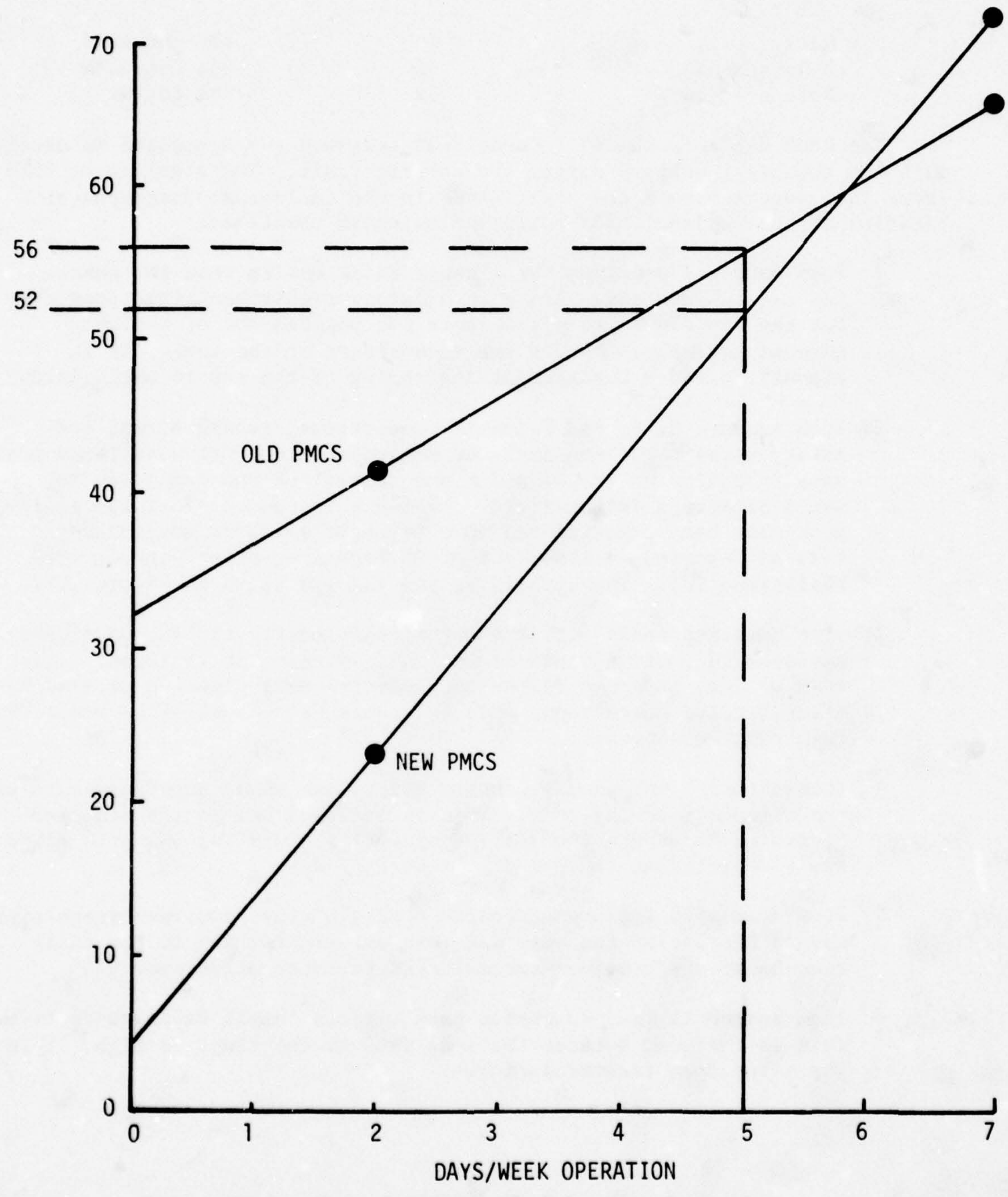


Figure IV-1. Annual Manhour Requirement Comparison

Table IV-2. Revised PMCS Manpower Impact

Operational Scenario	Annual Manhours Old	Revised	
Daily	65	71	10% increase
2 Days/Week	42	23	50% decrease
No operation	32	4	90% decrease

The PMCS table in the 10-1 manual was reviewed and discussed in detail with the technical writers during the on-site visit. The significant PMCS items that were reviewed are highlighted in the following paragraphs with notation of the rationale for their inclusion in the table:

1 Item number 3 provides for a check to determine that the antenna tip cap is in place. There is a safety requirement that provides for the tip cap to be placed over the pointed end of the whip antenna assembly. During the redo effort of the table, it is planned to add a requirement for taping of the cap to avoid loss.

2 Item numbers 5, 6, and 7 (cable connections, ground strap, and safety wire) have been included because of the increased frequency, usually daily, of installation and removal of the radio set to avoid pilferage in the field. Frequent instances of stolen equipment have been reported and have prompted a rather unusual field fix, as reported in Issue 302 of PS Magazine, dated January 1978 (Reference 10). The details of the fix are shown in Figure IV-2.

3 Item number 8 deals with the water drain on the antenna mount and has been included because of the daily washing of vehicles. This item will be expanded to include more frequent draining provisions after fording operations, when the table is redone. This was a red team recommendation.

4 Item number 9 includes a caution not to use water under pressure on the antenna matching unit. This is included due to the Standard Operating Procedure (SOP) for many of the operating units to flood their vehicles at the end of the working day.

5 Item number 10 includes specific checks of the receiver-transmitter mounts because of the wear and tear experienced due to the daily removal of the receiver-transmitters to avert pilferage.

6 Item number 11 is a check for good O rings on all audio connectors. This is included because the loss rate of the rings is high. This was a red team recommendation.

(Ed Note: Sounds good! This also applies to other AN/VRC-12 series radio sets. However, it's not recommended for use in training or tactical units. You use it only with the local commander's authorization.)

Figure IV-2. Radio Set Security

7 Item number 13 is a check to determine if moisture barriers are in place. This item is included based on arctic usage of the equipment.

8 Item number 15 applies to the operational check of the radio set. The check was not designated as before operation based on the daily removal of the equipment from vehicles. It was suggested by the red team that the responsibility of the supplying unit was to issue an operating set.

9 Item 22 relates to battery terminals. During the table redo effort, this step will be expanded to include checking for finger tightness of battery connections. It has been noted by the red team that field troops have been lifting battery terminals by application of excessive pressure when tightening connections.

The present PMCS for the AN/VRC-12 radio set represents an operator scheduled maintenance program primarily based on field experience and judgment of individuals knowledgeable in the equipment operation. Strong support must be given to justify elimination and/or modification of certain portions of the existing table. The re-do effort, scheduled subsequent to the issuance of the DA pamphlet "Guide to RCM for Fielded Equipment" will utilize RCM decision logic. Application of this logic must be supported by a FMECA or equivalent to provide the criticality data required to make sound decisions in structuring the scheduled maintenance program for the AN/VRC-12 radio set.

1.4.3 DMWR Scrub/Depot Work Policy Review

On 4 February 1977, a DA message (Reference 11) to all commodity commands called for the establishment of a program to perform in-depth reviews of DMWRs to achieve compatibility with RCM. A subsequent DARCOM message on 22 February 1977 (Reference 12) requested a milestone plan for the review of at least one high-overhaul cost end item from each commodity command to include time frames, methodology, and validation procedures. These messages initiated the DMWR scrub program for the Army and resulted in the identification of the AN/VRC-12 as the CERCOM candidate in the program.

As of the time of the on-site survey, no formal program had been established. However a meeting was held at Tobyhanna Army Depot (TOAD) in January 1978 to lay the groundwork for a proposed program. The significant events of the meeting included:

1 A briefing was given by Dr. Seymour Gordon, DARCOM, to the TOAD personnel on RCM.

2 Identification was made of areas of the AN/VRC-12 DMWR to be reviewed with RCM principles in mind - elimination of final tests that never reveal failures (depot personnel input) and refinement of cosmetic principles.

3 Mr. Seal will submit a DMWR review plan for depot concurrence. When this is accomplished, the completion date for the DMWR scrub program will be determined.

The AN/VRC-12 radio set and its subcomponents are returned to the depot primarily on the basis of field failure. Selected modules are replaceable at the organizational level while most are replaced at the general support unit. Among the organizational maintenance resources is a signal tracing device to facilitate isolation to faulty modules. At the depot, items are fault isolated and disassembled only to the extent necessary to complete repair.

The CERCOM program for the selection of depot overhaul candidates is contained in TB 750-252, "Review Periods of Selected Electronics Equipment for Overhaul" (Reference 13). This technical bulletin lists the mean time between overhaul for command managed equipments, to provide a means for determining the approximate time in which an item should be scheduled for a complete check of its combat reliability. Equipment undergoing inspection is not disassembled solely to check for serviceability of parts, subassemblies, and assemblies. If the item inspected is found to meet designated standards, it is continued in service. If standards are not met, the item becomes a depot overhaul candidate. TB 750-252 is applicable to the AN/VRC-12 radio set.

Review of the command RCM and depot files revealed correspondence dating as far back as 1970 which addresses finishing practices versus overhaul costs. More recent correspondence on 7 October 1977 (Reference 14) from the Director of Product Assurance to the Commander of TOAD addressed the same subject. The letter indicated that the position on physical appearance criteria proposed by the maintenance directorate be adopted. The proposed criteria included the following:

1 All questionable painted surfaces will be touched up or refinished at the discretion of the quality assurance element at the depot. OD color mismatch is permissible.

2 Bare metal areas or those which are rusted and corroded will be surface cleaned, primed, and touched up. Moisture fungus overspray, if required by specification, will be applied.

3 Slight dents that do not effect operations or seriously degrade appearance will be acceptable.

4 Slight scratches and abrasions will not be removed unless bare metal surfaces are exposed.

5 Chipped or dented dials or knobs will not be replaced unless the equipment operation or operator safety is affected.

6 Chipped and slightly damaged parts such as receptacles, plugs, cords, components, and piece parts will not be replaced unless the mechanical or electrical operation is affected.

7 Manufacturing defects that do not affect operation will not be corrected.

It is intended that the proposed criteria will be applicable only to equipment that is repaired or overhauled for distribution to regular Army units. CERCOM items programmed for foreign military sales, government furnished property, government furnished aerospace equipment, and military assistance programs will continue to be refinished to the requirements of TB SIG 355-2 "Depot Inspection Standards for Refinishing Repaired Signal Equipment" (Reference 15).

Operations at TOAD were discussed with personnel from the CME Division. The general opinion is that the depot is utilizing sound operating principles and is not engaging in unnecessary tasks during overhaul and repair operations. The depot personnel are cognizant of the attempt to lower overhaul costs and are looking for ways to reduce work requirements. For example, they feel that AN/VRC-12 components are adequately identified in technical manuals, and there is no need to strip equipment to restore reference designators. On the negative side, it is felt that the depot does not necessarily utilize their failure rate data to the best advantage. The data could potentially improve their operation if it were used.

As a result of reviewing the DMWR scrub program planning and depot operating policies, the following observations were noted:

1 The DMWR scrub program plan, as identified in the January, 1978 meeting at TOAD, is feasible and should result in work reduction and cost saving benefits.

2 The selection criteria for overhaul, i.e., on-condition inspection of items and repair of field failures, is in accordance with the basic principles of RCM.

3 CERCOM is now, and always has been, fully cognizant of high depot overhaul costs. They have identified the areas that offer the greatest potential for cost saving benefits for electronic equipment, i.e., physical appearance criteria and testing requirements.

1.5 CONCLUSIONS AND RECOMMENDATIONS

Based on the survey of the AN/VRC-12 RCM implementation effort by CERCOM, the following conclusions and recommendations are summarized.

1.5.1 Conclusions

1 Formal guidance from higher command levels for implementation of RCM was not provided to support the early RCM efforts of CERCOM.

2 There is a self-professed lack of resources within the command to perform a FMECA, which is a necessary ingredient to an effective RCM program.

3 Due to the inherent characteristics of electronic components, i.e., random failure rates and short T_{OS}; there is presently limited opportunity for application of RCM.

4 The revision effort on the operator's PMCS for the AN/VRC-12 accomplished integration of ESC. Furthermore, the revised PMCS now includes items relevant to field problems (red team survey recommendations), providing a sound scheduled maintenance base on which to apply RCM principles. However, no RCM guidelines or logic were utilized in the revision effort.

5 The approach being used in the development of the DMWR scrub and depot work policy review plan is proper. The areas of concentration - refinement of cosmetic principles and revision of testing requirements-indicate the greatest potential for reduced depot maintenance requirements and costs.

1.5.2 Recommendations

1 Resources should be identified within the command, or furnished to them, for performing a FMECA or equivalent effort.

2 Assistance should be provided to CERCOM in the identification of new techniques to enhance the implementation of RCM on electronic equipment.

3 The redo effort of the revised PMCS, as already ordered by the Director of Maintenance, should be supported through application of the guidelines in the draft DA pamphlet "Guide to RCM for Fielded Equipment."

4 The development of the plan to review AN/VRC-12 DMWR and depot work policies should be completed and implemented as soon as practical.

2.0 ERADCOM SURVEY

2.1 BACKGROUND

2.1.1 Purpose of Survey

The purpose of the survey was to evaluate the application of RCM to the AN/TPQ-37 (Artillery Firefinder) radar set.

2.1.2 Organization Surveyed

U.S. Army Electronics Research and Development Command (ERADCOM)
Fort Monmouth, New Jersey 07703

2.1.3 Date of Survey

1 Initial (via telecon) - 24 January 1978

2 On-site - 23 March 1978

3 Follow-up (via telecon) - 3 April through 5 May 1978

2.1.4 Persons Contacted

Mr. Richard Koster
Chief, Logistics Management Division

Lt.Col. Ott
Assistant Project Manager for Readiness

2.2 OBJECTIVES AND SCOPE

The survey of ERADCOM was conducted as a task supplementary to the CERCOM survey effort. The selected equipment under management control of ERADCOM was the AN/TPQ-37 (Artillery Firefinder) radar set. The AN/TPQ-37 radar set was identified as the developmental system candidate to be evaluated under the contract to assess the U.S. Army implementation of RCM.

The AN/TPQ-37 consists of an Operations Control Unit (OCU) configured in a S280 shelter and an antenna assembly which includes the transmitter and a portion of the receiver. A 2 1/2 ton truck carries the OCU. A 5-ton truck carries the 60 kW diesel generator for primary system power and tows the antenna assembly on an XM-832 dolly set.

The point of contact at ERADCOM was Mr. Richard Koster, Chief, Logistics Management Division. Mr. Koster was initially contacted by telephone 24 January 1978. At that time he was:

1 Apprised of the role of the Martin Marietta Corporation within the scope of the assessment contract.

2 Queried as to the status of RCM on the Firefinder system

3 Asked to forward to Martin Marietta all pertinent documentation related to RCM implementation on the Firefinder system.

The AN/TPQ-37 project office, located at Fort Monmouth, was visited on 23 March 1978 concurrent with the on-site visit to CERCOM. A discussion was held with Mr. Koster and Lt. Col. Ott, assistant project manager for readiness, to determine the RCM program status on the AN/TPQ-37 radar set.

2.3 RCM ACTIVITY

ERADCOM has provided to Hughes Aircraft Corporation (HAC), the AN/TPQ-37 system contractor, the following RCM documents and guidelines:

1 "Airline/Manufacturer Maintenance Program Planning Document, MSG-2" (Reference 16)

2 "CERCOM RCM Implementation Guide" (Reference 17)

3 AN/TPQ-37 radar set contract "Statement of Work" (Reference 18)

It was pointed out that the MSG-2 document was directed toward use on aircraft and the CERCOM RCM Implementation Guide was designed for use on fielded equipment. Appendix C to AMCP 750-16, DARCOM Guide to Logistics Support Analysis (LSA) (Reference 19), was intended for use on developmental systems. Mr. Koster indicated the Firefinder was not a developmental system but was in the low-rate initial production phase. In addition, Appendix C was not an applicable document at the time the Firefinder contract was let.

The guidance set forth in the contract Statement of Work (SOW) is very limited and does not provide the required detail for effective RCM implementation. The RCM paragraph from the SOW is quoted herein:

> "Reliability Centered Maintenance (RCM): the principle of RCM shall be followed in determining specific maintenance actions on the AN/TPQ-37. When developing the Maintenance Allocation Chart, consideration shall be given to designing preventive maintenance requirements in light of the maintenance philosophy of RCM. For example, automatic replacement of components at a specific time interval shall not be specified unless it can be shown that failure of that component would endanger personnel, equipment, or prevent the radar from meeting its overall availability requirements. The reference to be used for RCM is the "Airline/Manufacturer Maintenance Program Planning Document, MSG-2," dated 25 March 1970 (Enclosure)."

The ERADCOM emphasis is in attempting to influence the contractor's thinking toward RCM. The basic approach of HAC will be to identify wearout items and apply RCM to those selected candidates. To date, no results have been in evidence of the contractor's accomplishments. The proposed agenda for the Integrated Logistics Support (ILS) meeting (April 4 and 5, 1978) addressed the RCM accomplishments. Mr. Koster indicated in a telephone conversation, subsequent to the on-site visit, that no contractor accomplishments were reported at the referenced meeting. ERADCOM intends to actively pursue the status of contractor RCM accomplishments at all future ILS review meetings on the AN/TPQ-37 radar set.

The contractor is tasked with performing an LSA effort. However, the requirement to provide failure mode effects and criticality analysis (FMECA) has been excluded. This is a common occurrence in many equipment development efforts and severely hampers, or even negates, the use of Appendex C to AMCP 750-16 as the RCM implementation vehicle. When a FMECA is an exclusion item or LSA is not a part of an equipment development effort, alternate methods for RCM implementation must be provided.

2.4 CONCLUSIONS AND RECOMMENDATIONS

2.4.1 Conclusions

As a result of the ERADCOM survey the following conclusions are made:

1 The AN/TPQ-37 (Artillery Firefinder) radar set was erroneously identified as the developmental system candidate in the RCM assessment contract.

2 The RCM guideline documentation provided to the Firefinder contractor was inadequate for the following reasons:

- a The MSG-2 document is tailored for aircraft rather than electronic equipment.
- b The CERCOM implementation guide required modification and was intended for fielded equipment use.
- c The guidance set forth in the SOW is limited in scope and did not provide sufficient detail.

3 The exclusion of a FMECA, in support of the LSA effort for the AN/TPQ-37, is a frequent circumstance when establishing requirements for new system development.

2.4.2 Recommendations

Based on the preceding conclusions, the following recommendations are made:

1 The Army should identify a legitimate developmental system candidate on which to apply RCM, through the Appendix C guidelines.

2 ERADCOM should continue to monitor contractor RCM accomplishments on the Firefinder system. If the results are unsatisfactory, application of RCM should be made through the use of the DA pamphlet "Guide to RCM for Fielded Equipment" after system deployment.

3 The Army must identify alternate guidelines to Appendix C for application of RCM on developmental systems when LSA and a FMECA are not specified contractor tasks.

REFERENCES

1. DA Contract: DAAG-39-77-C-0169, "U.S. Army RCM Implementation Assessment," 23 August 1977.

2. Internal Correspondence, Director of Maintenance to directorate division chiefs: "Establishment of RCM Focal Point and Designation of RCM Action Officer," 30 September 1976.

3. "CERCOM RCM Implementation Guide," 25 March 1977.

4. DARCOM Message: "Review of PMCS, Integration of ESC," 2 June 1976.

5. DARCOM Message: "RCM Implementation Schedule for PMCS Revision," 1 October 1976.

6. CERCOM Correspondence to USAMMC: "RCM Implementation Schedule for PMCS revision on CERCOM Managed Items," 8 November 1976.

7. TM 11-5820-401-12, "Operator's and Organizational Maintenance Manual, Radio Set AN/VRC-12," September 1972.

8. TM 11-5820-401-10-1, "Operator's Manual, Radio Set AN/VRC-12 (used without Intercom Systems)", August 1977.

9. TM 11-5820-401-10-2, "Operators Manual, Radio Set AN/VRC-12 (used with Intercom Systems)," December 1977.

10. "PS Magazine," Issue 302, January 1978.

11. DA Message: "Reduction of Depot Maintenance Work Requirements," 4 February 1977.

12. DARCOM Message: "Reduction of Depot Maintenance Work Requirements," 22 February 1977.

13. TB 750-252, "Review Periods of Selected Electronic Equipment for Overhaul," 5 February 1971.

14. CERCOM Correspondence to TOAD: "Finishing Practices versus Overhaul Costs," 7 October 1977.

15. TB SIG 355-2, "Depot Inspection Standards for Refinishing Repaired Signal Equipment."

16. Airline/Manufacturer Maintenance Program Planning Document, MSG-2, 25 March 1970.

17. "CERCOM Reliability Centered Maintenance Implementation Guide," 25 March 1977.

18. AN/TPQ-37 Contract "Statement of Work."

19. AMCP 750-16, "DARCOM Guide to Logistic Support Analysis," with Appendix C, February 1978.

EXHIBIT V

AARCOM SURVEY REPORT

SUMMARY

The purpose of this survey was to assess the implementation of RCM on the M-110 self propelled howitzer through investigation and analysis of ARRCOM activities, plans, procedures and accomplishments. The main body of the survey consisted of an on-site visit to the Maintenance Directorate at Rock Island, Illinois in April, 1978, supported by telecons before and after this visit, and a thorough in-depth review of all available pertinent documentation.

ARRCOM management and RCM action personnel demonstrate a positive, interested attitude toward achieving RCM benefits. An RCM Implementation Team to control RCM activities for each weapon system has been established as a special effort, distinct from DMWR Scrub, On Condition Maintenance, and Army Oil Analysis Program. SOP No. 750-11 established authority, facilities procedural steps, and funding for the team; and monthly meetings are held to track progress. RCM progress on M-110 SP howitzer has completed only the first step of the required process but M-60 activity has passed the sixth step. Since RCM procedures and plans for both systems are identical, review of M-60 accomplishments has been made which should correlate reasonably with expected M-110 progress.

Guidance from higher commands, including decision logical and terminology definitions, was insufficient to prevent errors of omission and interpretation in engineering analysis usage and development, application of decision logic, and determination of M-60 PMCS activity, although the work attempt was generally appropriate and responsive. Comparative analysis was accomplished on M-60 PMCS, but no plans for identifying an audit trail on sustaining engineering have surfaced.

ADAP is scheduled for September 1978 initiation and OCM is under study, both of these for turrets (including gun recoil mechanism). A sample test data collection program for artillery is under way that should produce dependable data for RCM use in 1979 and 1980.

Exhibit V contains a number of recommendations from Martin Marietta. The following pertain directly to ARRCOM activity:

1 Analyze RCM principles and concepts and develop a thorough understanding of RCM strategy through assignment of personnel possessing sufficient training, background, and experience to conduct engineering research and technical analysis for equipment maintenance.

2 Develop and formalize RCM logic that is specifically designed for the type of weapon system under consideration. Separate and distinct decision logic probably will be required for PMCS and for DMWR scrub.

3 Develop and document failure modes and effects analysis for each weapon system, and, where applicable, prepare supporting fault detection and location analysis to supply data needed for valid decision logic processing.

4 Retain and/or implement all RCM-related programs applicable to armored equipment that demonstrate success in meeting the primary objectives of RCM.

5 Continue the acquisition and improve internal dissemination of accurate, dependable, and useful field operating and maintenance data to provide a solid, provable basis for future maintenance planning.

EXHIBIT V

ARRCOM RCM SURVEY REPORT

1.0 BACKGROUND

1.1 Purpose of Survey

Evaluation of application of Reliability Centered Maintenance (RCM) concept to maintenance programming for M-110 Self Propelled Howitzer by the U.S. Army.

1.2 Organization Surveyed

U.S. Army Armament Materiel Readiness Command (ARRCOM)
Rock Island Arsenal, Rock Island, Illinois 61201

1.3 Date of Survey

a Initial (via telecon) 17 January 1978

b On-site (Rock Island) 4 to 7 April 1978

c Follow-on (telecons) intermittent between 10 April and 30 June 1978

1.4 Persons Contacted

Col. William T. Green DRSAR-CS
Chief of Staff, ARRCOM

Maintenance Directorate

Col. James N. Payne DRSAR-MA
Director of Maintenance

Mr. John H. Alcott DRSAR-MA
Deputy Director of Maintenance

Major Alvin Peterson DRSAR-MAO
Operations Officer
Directorate for Maintenance

Mr. Harry Alcorn DRSAR-MAL-F
M-110 DMWR Scrub Team Leader
Directorate for Maintenance

Mr. Gerald R. Anderson DRSAR-MAB
Directorate for Maintenance

Mr. Joseph Dagnon DRSAR-MAB
Directorate for Maintenance

Mr. Otto Ehm DRSAR-MAL
Directorate for Maintenance

Mr. Paul Fellman DRSAR-MAL
Directorate for Maintenance

Mr. Michael Hart DRSAR-MAP
Directorate for Maintenance

Mr. John Haney DRSAR-MAL
Directorate for Maintenance

Mr. Henry D. Martin DRSAR-MAL
Directorate of Maintenance

Mr. Terry Piatt DRSAR-MAL-ST
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Sergeant Major F. Pradziad
DRSAR-MAO
Directorate for Maintenance

Mr. S. R. Schirru DRSAR-MAB
Directorate for Maintenance

Mr. Richard D. Smith DRSAR-MAL
Directorate for Maintenance

Mr. Jesse Trent DRSAR-MAL-SS
Directorate for Maintenance

Mr. James Varcho DRSAR-MAL
Director for Maintenance

Mr. Ed Vaughn DRSAR-MAL-F
Directorate for Maintenance

Product Assurance Directorate

Mr. Leslie E. Murray DRSAR-OA
Product Assurance Directorate

2.0 OBJECTIVES AND SCOPE

The objective of the RCM implementation assessment survey, performed in accordance with task 4.0, subparagraph a, of contract DAAG 39-77-C-1069, was to determine the status of RCM implementation and to evaluate the degree of compliance with Department of the Army (DA) requirements applicable to the M-110 SP Howitzer. Related programs initiated before RCM formalization in addition to the established RCM program were investigated in the survey. Areas investigated included instructions, directives, guidance and regulations issued to ARRCOM by higher authority; response by ARRCOM to RCM requirements; directives and procedures issued by ARRCOM; contents of RCM and RCM-related programs; and achievements in the implementation of these programs.

The assessment of RCM implementation on the M-110 was conducted in three phases: (1) becoming acquainted with ARRCOM activities pertaining to M-110 maintenance planning and the apparent status of RCM implementation, (2) a visit to the Rock Island Arsenal for an on-site review of current efforts, discussions with involved personnel and acquisition of documents, forms, worksheets supporting the approach, and (3) a detailed inspection, review and analysis of the RCM implementation work accomplishment and goals attained to date.

The first phase was initiated by a telecon with the ARRCOM RCM Action Officer to obtain preliminary information on M-110 RCM plans, actions and progress, to ascertain extent of previous maintenance revision programs pertaining to RCM elements, and to request copies of directives, guidelines, and procedural instructions. The balance of the first phase consisted of an in-depth review of DoD, Army, DARCOM and MRSA documentation pertaining to M-110 functions, mission, design features, system components, armament, and maintenance programming in effect both before and after the advent of RCM.

The on-site survey, conducted during the week of 4-7 April 1978, consisted of interviews with ARRCOM personnel of various rank and position in several offices of ARRCOM, with most interview time spent in the Directorate for Maintenance. The aim of these discussions was to identify accomplishments and problems associated with the formal and informal tasks of RCM application, to determine what requirements and guidance had been received and to evaluate personnel receptiveness to RCM implementation.

Follow up telecons were made during the third phase to obtain additional supporting information, to verify verbal statements regarding interpretation of document terminology, and to clarify points of understanding. The detailed insepction analysis for information received in the first two phases indicated that confining the review to M-110 RCM activities alone would not yield an accurate picture of ARRCOM emphasis and efforts to accomplish full RCM application, so some analysis time was given to examination of M-60 Tank RCM progress.

Throughout the entire assessment period, ARRCOM command and operating personnel were most cooperative and supportive of the aims and efforts of the Martin Marietta survey showing considerable enthusiasm in favor of the RCM program and its expected benefits. Procedural guidance and in-depth interpretation of RCM principles was requested and accepted readily by RCM action personnel. It was apparent that ARRCOM management emphasis intended to place the command in a posture suitable for complete and effective implementation of RCM.

Results of the survey investigation are contained in the following paragraphs describing information acquisition, current RCM application efforts, problems encountered, and accomplishments to date.

3.0 RCM APPLICATION

In the first telecon, January 1978, it was learned that revisions of M-110 Operator's Manual (Reference 1) and Organizational Maintenance Manual (Reference 2) were scheduled in March, with draft completion by July, 1978. Revision of M-110 Depot Maintenance Work Requirements (DMWR) draft had been completed, and 30 vehicles were scheduled to be overhauled during FY 78 as a pilot program to validate the revised draft DMWR. At this point in time, the ARRCOM RCM Action Officer was not aware of any other applicable M-110 maintenance revisions program that contained elements having relationship to RCM principles and strategy.

A Reliability Centered Maintenance Implementation Team (RCMIT) was chartered in September, 1977, with a chairman, 14 principal members, and 3 alternates to hold monthly and special meetings to guide and monitor the progress of RCM activities. Standard Operating Procedure (SOP) No. 750-11 (Reference 3) was published on 12 January 1978, detailing the responsibilities of the team and requirements for task accomplishment on all maintenance-significant, in-service materiel systems. Funding was authorized in consonance with other on-going priorities/functions. RCMIT was authorized a direct line of communication to the Director of Maintenance, ARRCOM, with necessary facilities and administrative support provided by the directorate.

In the 28 September 1977 meeting of RCMIT, (Reference 4) a schedule of submission dates for each system RCM plan was established, with the M-110 SP howitzer date falling in November, 1977, and all systems plans due by December. In January, 1978, a schedule of publication dates for manual revision draft completions (Reference 5) was distributed. This schedule

calls for all revisions to be delivered by November 1979 and sent to the Adjutant General (TAG) by August, 1980.

During the interviews conducted in the course of the on-site review, it was found that the first steps in the manual revisions for the M-110 (References 1 and 2) were in progress during that same period of time (4-7 April), and an accurate assessment of RCM revision adequacy would not be practical until a later date. However, the first drafts of TM 9-2350-215-20 (Reference 6) and TM 9-2350-215-10 (Reference 7) on the M-60/M60 A1/M 60 with Add-On Stabilization (AOS) had been completed and sent to other ARRCOM branches and divisions for comments and/or corrections. Because RCMIT plans and procedures for draft revisions to M-110 SP howitzer maintenance manuals are identical to those on the M-60 tank, and because conversations with RCM action personnel on both weapons systems indicated uniform approaches would be utilized, it would seem appropriate to evaluate RCM implementation by review of instructions, procedures, progress, and results of the M-60 RCM effort. This review would yield a valid evaluation of the ARRCOM approach, methodology, decision logic, and draft changes proposed for comparison with current manuals. Even though the mission and functions of the M-60 tank are not the same as M-110 SP howitzer, the maintenance requirements are similar, and an assessment of ARRCOM RCM implementation on the tank should reasonably correlate with an assessment of the intended RCM implementation action on the howitzer.

Basically, there are ten steps in the procedure established by ARRCOM to accomplish revisions to the Preventive Maintenance Checks and services (PMCS) listed in the maintenance manuals:

1 Perform "old manual" tasks via shop simulation to determine the exact time required/materials needed

2 Apply DARCOM Logic
(January 1978 Draft Guide for Non-aeronautical equipment)

3 Complete the Single Task Worksheet (ARRCOM Form 980) (Maintenance Process Analysis)

4 Establish new PMCS tasks (to eliminate unnecessary, restore reliability)

5 Estimate new task elapsed times (based on times recorded for old tasks)

6 Compare new procedures to old PMCS procedures (no. of tasks, total time)

7 Coordinate proposed procedures with other ARRCOM branches/divisions/directorates

8 Review new procedures as required by corrections/comments

9 Perform new manual tasks to determine the exact time required/ materials needed

10 Prepare the final report and forward it to other commands for coordination.

This procedure is presented here to display the depth of planning and organization established by the RCMIT charter and SOP 750-11 (Reference 3). As of the date of the survey, Step 6 had been completed on the M-60, and Step 1 was finished for the M-110. Evaluation of the problems encountered and success to date is included in paragraph 5.0.

4.0 RCM RELATED PROGRAMS

4.1 Reduction of PMCS and Project LEAP, Issue 127

Immediately prior to its activation of RCM implementation activities, ARRCOM was involved with reduction of PMCS and the LEAP (Logistics Efficiencies to Increase Army Power) program, two projects of the Army which contain common elements, which were established to achieve similar goals. To support these projects, ARRCOM Maintenance Directorate established and chartered a LEAP Implementation Team (LEAPIT) to coordinate internal efforts and ensure full compliance with directives. The M-110 SP howitzer was not one of the 12 target systems included in Project LEAP, Issue 127. ARRCOM involvement was restricted to the 105 mm M-109 howitzer SP, for which LEAPIT was chartered. Reference 13, Apendix D, shows that the effort accomplished a 52 percent reduction in total number of M-109 maintenance task requirements, representing an estimated 34 percent savings in maintenance manhours.

In accordance with DARCOM's June 2, 1976, letter (Reference 12) directing the commodity commands to revise PMCS and to eliminate ESC manuals as a separate publication, ARRCOM drafted changes to TM 9-2300-216-10 (Operator's Manual for M-107, M-110 and M-110A1) dated 17 May 1976. The changes have been published by Headquarters, Department of the Army on 28 July 1977 (Reference 1).

4.2 Army Oil Analysis Program

The Army oil analysis program (AOAP) is a series of tests which provide an indication of the physical condition of engines or engine parts, gear boxes, and transmissions. The concentration of contaminates such as wear metals, water, rust particles, chemicals, and oil dilution are some of the problems that the analysis uncovers.

The Army initiated the oil analysis program in 1957, when aircraft were placed under the program in an effort to enhance flight safety.

Based upon the results of a test program conducted at Ft. Hood, Texas, Headquarters, III Corps, in a letter to FORSCOM (Reference 16), recommended

that the oil analysis program be extended to non-aeronautical equipment. FORSCOM endorsed the III Corps position and forwarded a recomendation to DA (Reference 17) that this extension be approved. Department of Army, in a second endorsement (Reference 18), approved the III Corps recommendations and directed its implementation.

To date, AOAP on the M-110 has been implemented through TARCOM since they have cognizance over the engine, hull and chassis. The total number of vehicles shown in Exhibit III, as included in AOAP by TARCOM, includes the M-110 units. The turret assembly including the 8-inch howitzer is controlled by ARRCOM and currently it is not being evaluated through spectrometric analysis of oil samples. The Martin Marietta investigator was advised verbally that the gun is scheduled for inclusion in AOAP in September 1978, however documentation of this plan was not available. There appears to be some doubt among ARRCOM equipment specialists that AOAP will be effective in determining impending failures in the gun recoil mechanism.

AOAP samples of oil are taken at regular intervals (either hours or miles), thereby constituting scheduled maintenance, or on condition inspection under RCM terminology. However, the procedural concept is a form of condition monitoring, since the objective is to determine degradation of equipment reliability and to accomplish replacement of the assembly prior to actual failure.

4.3 On-Condition Maintenance

On-Condition selection of combat vehicles for depot overhaul is a technique that utilizes the results of periodic inspections performed by a qualified team to determine which vehicles are most in need of depot overhaul. Specifically, this method of selection consists of evaluating the results of the inspection of certain key items which are significant indicators of the vehicle's condition. These individual items are numerically weighted, relative to their importance and condition. The sum of these values is used to establish a profile index for each vehicle. Vehicles are selected for depot maintenance based on this index, with those having the worst rating selected first. This selection method is a vast improvement over the previous hardtime criteria of mileage or calendar time.

Department of Army tasked AMC (now DARCOM) early in 1972 to develop a more realistic peace time overhaul criteria. AVSCOM (now TSARCOM), in coordination with AMC, proposed the On-Condition Maintenance concept for selecting Army aircraft for overhaul. The program was initiated in 1973.

In a memorandum from the Office of the Assistant Secretary of the Army to the Deputy Chief of Staff for Logistics (Reference 14), directions were given to extend the aircraft RCM logic to other Army commodities. The DA letter (Reference 15), delegated to DARCOM the responsibility to establish procedures and methodology to achieve an On-Condition depot level selection criteria, and to develop pilot programs on equipment representative of tracked and wheeled vehicles.

Due to division of responsibility on armored equipment such as the M-110 SP howitzer, ARRCOM supported a study conducted by TARCOM to define a new overhaul policy for their vehicles. The study, using RCM principles, was conducted for three primary areas of overhaul selection process: technical, management, and cost.

In the technical area, the objective was to develop a technical inspection procedure through which the vehicle's need for overhaul could be determined. this included the identification of certain key indicators to be scrutinized to determine the vehicle's current condition, and through the use of the proper test measurement and diagnostic equipment to predict when the vehicle will require overhaul. The goal was to be able to predict at least two years in advance the time at which the vehicle would require overhaul.

In the management area the objective was to devise a system to permit the selection of those vehicles most in need of overhaul, and ensure their timely arrival at the depot. Management divided those tasks into areas pertaining to the vehicles selection process and to the evaluation process. The former is concerned with the assembly of data necessary to make a choice of vehicles to be overhauled, and the process by which they are routed to the depot. The latter is focused on the administration and management of a system for producing the vehicle condition evaluation profiles and fleet profiles.

In the cost area, each step of the process was identified and isolated for use in performing the cost effectiveness analysis to determine the method of selecting combat vehicles for overhaul.

The study included the turret (ARRCOM cognizance) and the hull and chassis (TARCOM cognizance). A field validation test of 12 vehicles (M-60A1, M-109, M-551 and M-113A) was conducted at Ft. Hood, with results scored by TARCOM. Recommendation of a pilot test program followed.

The pilot program has been initiated, whereby all M60A1 tanks in CONUS with 5000 miles or more will be inspected by local units in accordance with instruction provided by TARCOM. The results of the vehicle condition evaluation are forwarded to TARCOM, where the vehicles needing overhaul are identified.

Under the pilot program inspection and vehicle selection conducted during March, 1978:

1 60 vehicles with excess of 6000 miles were identified for evaluation, 13 were selected for overhaul, 44 vehicles with over 5000 miles were identified for evaluation, and 15 were selected for overhaul.

2 28 vehicles with less than 5000 miles were submitted by their owner for evaluation and 14 were selected for overhaul.

3 A total of 132 vehicles were subjected to the vehicle condition evaluation, and 42 (31.9 percent) were selected for overhaul.

Within the ARRCOM Maintenance Directorate, a study is being made of the effectivity of this program in relation to turrets and also for extension of OCM to include towed and self-propelled howitzers (including M-110). It is generally believed that the program will be viable and cost effective, although those portions of tracked vehicles under TARCOM responsibility most likely will be the determining factor for overhaul rather than ARRCOM's equipment area.

4.4 DMWR Scrub

Depot Maintenance Work Requirement (DMWR) is a document which provides, in explicit terms, the scope of depot or contract maintenance operations to be performed on an item of equipment; types and kind of material to be used; quality of workmanship; repair methods, procedures and techniques; modification requirements; fit and tolerances; equipment performance parameters to be achieved; quality assurance discipline; and other essential factors which prescribe maintenance operations to ensure an acceptable and cost effective product as the result of overhaul. The DMWR is prepared in accordance with the contents of Military Specification (Reference 19).

DA Message (Reference 20), established the requirement to conduct an in-depth review and revise the DMWRs for the purpose of achieving compatibility with RCM. This direction was followed by a DARCOM message (Reference 21), which directed ARRCOM to select at least one high overhaul cost end item on which to perform the DMWR review. The M-110 was selected by DRSAR-MA as a pilot program, however this scrubbing activity was not included in RCMIT responsibility under Reference 3 by ARRCOM.

The draft revisions for M-110 DMWR Scrub have been prepared for use with validation test runs at the depot. The entire procedure including methodology used and current status was discussed at some length with the team leader at DRSAR-MAL-F. In March, 1977, DRSAR-MA initiated a critical review of selected DMWRs for the M-110 Howitzer to ensure that they were purged of all cost incurring requirements that are not essential to delivery of a quality product to the user. A letter to Letterkenny Army Depot, (Reference 10) requested that two DMWRs (References 8 and 9) be reviewed against the inspect-and-repair-as-required (IRAR) type process, to disclose any areas of question since IRAR assets are processed at one half the cost of items processed in accordance with DMWR requirements. Feedback from the depot was to be used for draft revisions to the DMWRs.

DA Form 2028 (Reference 11) was utilized by DRXLE-QA to forward change recommendations to ARRCOM, and these changes were incorporated in the draft revisions without material alteration by DRSAR-MAL. The Martin Marietta investigator was advised that RCM decision logic was not utilized by ARRCOM personnel in preparing the proposed revisions and that is was not known whether any such logic was used by Letterkenny personnel. Reference 22 states that it is the command's intent to implement RCM into the M-110 DMWRs and then use them in a test depot overhaul program. It also requests that the revised DMWRs be used in FY 78 overhaul program of thirty vehicles and that dollar reduction in overhaul cost for each vehicle be reported back to DRSAR-MAL-F.

4.5 Sample Test Data Program

A major hindrance to the use of engineering analysis on Army equipment has been the lack of dependable field usage data, failure rates, amount of repairs and spare parts required. Having noted the need for such data in the past, ARRCOM established a sample test data program to collect reliability, availability and maintainability (RAM) information on field artillery. The two year program was established in mid-1977 on approximately 1,100 units including 80 M-110 SP Howitzers. Figures 5-1 and 5-2 show the scope of information submitted to ARRCOM by the field user (ARRCOM Forms 260 and 103) and this is inputted to a computer program for data analysis and categorization. Outputs include miles traveled, engine hours, towing hours, winch hours, rounds fired, active maintenance time, total downtime, operating time, and operational availability. Also given are ratios (maintenance man hours per mile, maintenance per rounds fired) for each maintenance level, plus the number of maintenance occurrences and number the of parts replaced for each system.

It is expected that this program will yield the information that is needed for engineering analysis of weapon system equipment for RCM decision logic application. It should also be directly applicable to comparative analysis usage. Although the final report will not be published until the end of FY 79, some of the preliminary test data analysis is being made available on computer printouts for ARRCOM directorates prior to completion of the test period.

5.0 ASSESSMENT

In order to accomplish a critical appraisal of maintenance planning for the purpose of understanding or interpreting its relationship to RCM (or to be used as a guide for future action), it is necessary to consider the salient factors that are considered applicable to RCM today:

1. A formal, positive, restrictive definition of RCM has not been established by the Army or DoD

2. The principles of MSG-2 are considered to be the basis of RCM strategy and concept

3. The primary objective of RCM is to retain inherent equipment reliability at the lowest overall cost

4. Achieving this objective can include some or all of the following items:

   a. Engineering anlaysis of historical equipment data

   b. Processing data through decision logic

   c. Eliminating unnecessary maintenance tasks

d Replacing hardtime criteria with on-condition inspection or condition monitoring

e Replacing on-condition inspection with condition monitoring

f Adding new maintenance tasks only if they are cost effective

g Retaining restoring inherent equipment reliability (by PMCS or overhaul)

h Reducing maintenance tasks (PMCS and overhaul)

i Reducing maintenance costs (PMCS and overhaul)

ARRCOM activities in implementation of RCM have been organized to follow the guidelines established by DARCOM, although interpretation of the guidelines has resulted in varying degrees of accomplishment of the nine

items listed in 5.0 above. Assessment of ARRCOM success in accomplishing each of the items is given below:

Engineering Analysis of Historical Equipment Data (a, above)

No evidence has been discovered to indicate that historical data such as failure rates, failure modes and effects, or fault detection data has been made available or utilized by RCM analysts for M-110 PMCS revisions, M-60 PMCS revisions or M-110 DMWR scrub. Personal experience in the field, shop simulation of maintenance tasks, and engineering judgment have formed the basis of determination of draft changes to maintenance and overhaul tasks.

Processing Data Through Decision Logic (b, above)

RCM activity on M-110 PMCS revisions has not progressed to the point of application of decision logic. RCM activity on M-60 PMCS revisions included use of the decision logic provided by DARCOM in Jnauary, 1978 (Reference 23). The original logic provided by DARCOM that was based on MSG-2 format was verbose, confusing and difficult to use by ARRCOM RCM analysts, so permission was received to use the draft logic diagram, Figure 5-1. This logic also caused some confusion due to the words "PROPOSED COMPONENT INSPECTION" in the upper left corner, and due to the "yes" path from question No. 2 leading to question No. 6.

Two RCM analysts, working independently of each other in ARRCOM, interpreted the word "failure" in the first four questions to mean "failure to accomplish the maintenance task" rather than "failure of the maintenance significant item (MSI)". Obviously, these two interpretations of "failure" could yield different answers and possibly lead to different maintenance processes. It is also noted that a "yes" answer to question No. 2 should not lead the analyst to question No. 6, since the accepted definition of hidden function means that

degradation cannot be obvious to operator or crew during operation. It is understood that these guidance problems are corrected in a revised draft by DARCOM, but the logic diagram shown in Figure 5-1 is the one used by ARRCOM for RCM changes to M-60 PMCS.

No evidence has been revealed to indicate that RCM decision logic was used in DMWR Scrub effort to revise overhaul requirements for M-110 SP Howitzer.

Eliminating Unnecessary Tasks (c, above)

A comparative analysis was made by ARRCOM M-60 RCM analyst to show tasks eliminated by comparing the total number of tasks and the man-hours required for the PMCS contained in the current manuals and the same factors as proposed in manuals revised per RCM application. This comparison and reduction, with slight modification by Martin Marietta to simplify evaluation, is shown in Table V-1.

TABLE V-1

M-60 Tank RCM Results

	PMCS OLD MANUAL	RCM/PMCS NEW MANUAL	REDUCTION
Operator's (-10) Manual	88 Tasks 288 Man/Minutes	47 Tasks 250 Man/Minutes	41 Tasks (47%) 33 Minutes (13%)
Organization Maintenance (-20) Manual	58 Tasks 407 Man/Minutes	27 Tasks ?	31 Tasks (53%) ?

The man minutes given in column 2 ("new manual") are based on actual times required to perform the "old" tasks in shop simulation, as established in ARRCOM procedural steps 5 and 1. However, for the Organizational Maintenance manual, the items for the "old" tasks would not correlate sufficiently with "new" tasks to provide valid comparison, hence the question marks were entered in columns 2 and 3. These figures are based on a cycle of one each inspection (before, before firing, during, after, after firing, weekly and monthly) for the operator's manual.

Determination of the validity of deleting the tasks (41 in Operator's manual and 31 in Organization Maintenance manual) cannot be discerned due to the lack of an engineering analysis of field experience data. Judgement of the equipment specialist based on personal field experience was used for processing of tasks in the "old" manual through RCM decision logic. Those tasks which were eliminated in the draft revisions appear to be non-essential, and it is believed in DRSAR-MAL that some of these were not actually being accomplished by field maintenance personnel due to being non-effective.

Replacing Hardtime Criteria with On Condition Inspection or Condition Monitoring (d, above)

A considerable number of hardtime limit tasks in the "old" manuals have been replaced with on condition inspections or condition monitoring in the proposed revisions. The potential for manpower savings in this area has been, and continues to be, a prominent consideration factor during application of the decision logic by ARRCOM RCM analysts. It is believed that success is being achieved in this area, but verification of the accuracy and validity of the changes is not feasible in the absence of usage and failure rate data.

Replacing On Condition Inspection with Condition Monitoring (e, above)

This type of change has also been effective in the draft revisions. Assessment of this item is virtually the same as for item (d) above.

Addition of Cost Effective Maintenance Tasks (f, above)

No evidence has been made available to indicate that any potentially cost effective tasks have been added to prevent field failure or deterioration in the M-60. However, the Martin Marietta investigation revealed two field-encountered problems, not covered in M-60 proposed revisions, which might be averted by application of condition monitoring or on condition maintenance tasks. These two problems are shown in Table 5-2 along with the M-60 RCM analyst's explanation for not including them in the drafts. Lack of mention of these problems or including a related task would indicate insufficient attention was given to adding new tasks that could be cost effective. This demonstrates the need for the entire RCM processing technique since preventive task addition is the result of inductive application of FMEA data in the decision logic process.

Retaining or Restoring Equipment Reliability (by PMCS or Overhaul) (g, above)

The effectiveness of the M-60 PMCS task revisions in retaining or restoring equipment reliability will be determinable after the revised manuals have been issued and the resulting equipment usage and failure rate data can be compared with the sample test collection data now in progress. Generally, this is also true of the M-110 DMWR scrub effort, however, serviceability of the thirty M-110 howitzers to be overhauled in the test of draft DMWRs for hull and turret will provide a reasonable estimation of change benefits.

Reducing Maintenance Tasks (PMCS and Overhaul) (h, above)

Based upon the comparative analysis developed by ARRCOM for the M-60 PMCS revisions (Table 5-1), considerable task reduction has been accomplished (53% in the Organization Maintenance manual and 41% in the Operator's manual). Considerable task reduction in the two M-110

DMWRs is also apparent although a comparative analysis has not be prepared. Also in RCM-related programs previous to RCM initiation, maintenance tasks had been reduced under the 1976 programs for elimination of ESC and reduction of PCMS for M-60, M-110 and M-109 and other armored equipment.

Reducing Maintenance Costs (PMCS and Overhaul) (i, above)

In order to determine actual savings potential of reduced PMCS it is necessary that an operating scenario be available delineating equipment reliability requirements, estimated mean usage hours per day and per firing day, mean on-off cycles per day, number of operating days per month, environmental conditions and other pertinent factors. Considerable effort was expended by the Martin Marietta investigator to determine a representative or average monthly operating scenario for the M-60 tank or similar item in order to estimate dollar savings of the comparative analysis prepared (Table 5-1) by ARRCOM. However, the type and frequency of usage varied so greatly between the various operating organizations and their yearly operating schedules that a representative scenario could not be developed. It is possible that quantification of savings potential can be accomplished from the report of the first twelve months of the sample test data collection program which should be available at end of FY 78. A subjective review of the proposed RCM revisions to PMCS for the M-60 tank indicates that manhour costs will be reduced as compared to the currently PMCS requirements.

Estimated cost of overhaul of an M-110 howitzer under the test of the scrubbed DMWR was not made available to the survey and it may not have been calculated to date. The current cost is approximately $100,000. per M-110 overhauled with the currently applicable DMWR, and Reference 10 indicated that assets processed under IRAR cost one half as much; therefore, if the scrubbed DMWR follows the IRAR process with estimated 50% saving the new cost of overhaul should be in the neighborhood of $50,000 each. Based on 60 M-110 howitzers overhauled per year, (1979 to 1984 period) yearly savings should be approximately $3.0 million. Additional savings could result if the study of the OCM program for selection of overhaul candidates can feasibly be applied to M-110 as discussed in paragraph 4.3.

6.0 CONCLUSIONS

It is concluded that a strong, compliant effort to implement RCM on tanks and howitzers has been started by ARRCOM and supported with command emphasis. Some progress beyond the planning stage into draft revisions, has been accomplished in spite of difficulties from inadequate guidance and resulting interpretation errors. Several inadequacies in program planning, instructions and directives are noted in the specifics given below.

6.1 PMCS Revisions for M-110 SP Howitzer:

1 Insufficient resources available. Only one man per weapon system is available for RCM analysis, and then not full time. An equipment specialist was assigned rather than an engineer trained in technical research and analysis. Also, assignment was made to an M-109 specialist requiring familiarity development for M-110.

2 Field usage and failure rate data are not available at the time of RCM processing. This, plus the size and complexity of ARRCOM organization inhibits cross-flow of information between branches and divisions.

3 Insufficient guidance was received pertaining to definition, background justification and procedures of RCM.

6.2 PMCS Revisions for M-60 Tank

1 Insufficient resources available. This conclusion is identical with that of M-110 above, except that the equipment specialist assigned was familiar with M-60 equipment.

2 Field usage data and failure rates are not available at proper time for RCM revisions, and cross-flow of data between ARRCOM offices is less than optimum.

3 RCM implementation guidance such as RCM definition, clarification of terminology, understanding of basic RCM strategy, and procedures, was insufficient and thereby retarded success. This was identified by lack of development of either MSI list, or FMEA, with resulting interpretation and omission errors (see paragraphs 5.0(b) and 5.0(f) and Table V-2).

TABLE V-2

ERRORS/OMISSIONS IN NEW PMCS (M-60 TANK)

ITEM	FAILURE MODE CAUSE AND EFFECT	COVERED IN OLD PMCS	COVERED IN NEW PMCS	EXPLANATION
LOADER'S SAFETY SWITCH ASSEMBLY	CAUSE: SOLENOID OUT OF ADJUSTMENT EFFECT: GUN WILL NOT FIRE	NO	NO (LUBRICATE PARTS AT POINTS OF CONTACT IS INCLUDED IN -20 MANUAL)	"I DID NOT KNOW ABOUT THIS PROBLEM" (PER ANALYST)
BREECH OPERATING MECHANISM	CAUSE: SPRINGS WEAKEN REQUIRING GREATER ADJUSTMENT, NOT REPLACED UNTIL FAILURE OF FIRING PIN CONTACT. EFFECT: GUN WILL NOT FIRE	NO ADJUSTMENT NOT MENTIONED (FUNCTIONAL CHECK IS INCLUDED)	NO SPRING ADJUSTMENT AND REPLACEMENT NOT MENTIONED (FUNCTIONAL CHECK IS INCLUDED)	"THIS IS CORRECTIVE MAINTENANCE AND NOT APPROPRIATE TO PMCS" (PER ANALYST)

6.3 DMWR Scrub for M-110 SP Howitzer

DMWR draft revisions for Reference 8 were reviewed to determine the validity of changes recommended in consonance with RCM principles and strategy. Considerable changes and deletions were noted. Some qualified statements in the original document, such as "replace items that do not meet original manufacturing specification requirements" were changed to unqualified statements, such as "replace if unserviceable". This in effect gives greater latitude to the depot, and such latitude was specifically requested by Reference 10 when the IRAR type process was called out for consideration of DMWR revisions. Apparently ARRCOM considers IRAR to be the same as RCM. IRAR, however, is applicable to a single, individual unit which has been submitted to depot for preshop analysis and repair as required by that unit's condition; whereas, RCM methodology is designed for application to all MSIs and for determination of overhaul tasks for all units overhauled. In the example given above, it would appear that utilization of engineering analysis and RCM decision logic would yield a qualified DMWR statement that would specify tolerances acceptable for serviceability. A misunderstanding of basic RCM principles is apparently the direct causative factor in equating RCM with IRAR for DMWR scrubbing purposes. Lack of sufficient guidance in RCM strategy is concluded to be the underlying, indirect cause. Lack of inclusion of the DMWR Scrub effort in RCMIT cognizance is probably a contributing factor.

Assessment of overall ARRCOM actions toward implementation of RCM indicates that this command is endeavoring to achieve the benefits of the program, and if provided the appropriate assistance through detailed instructional guidance, the inadequancies of their program can be easily corrected.

7.0 RECOMMENDATIONS

Based upon the information, assessment and conclusions contained in this exhibit, the following recommendations pertaining to M-110 are tendered:

1. Develop and publish a formal RCM program definition that is fully defined with measurable goals and established procedures.

2. Develop guidance and instructional courses for the benefit of readiness command personnel to eliminate, insofar as possible, lack of understanding and interpretation differences.

3. Analyze RCM princples and concept and develop a thorough understanding of RCM strategy at command working level through assignment of personnel possessing sufficient training, background and experience to conduct engineering research and technical analysis for equipment maintenance.

4 Require the development and documentation of RCM decision logic specifically designed for the type of weapon system under consideration. Separate and distinct decision logic probably will be required for PMCS and for DMWR scrub.

5 Require the development and documentation of a Failure Modes and Effects analysis for each weapon system, and, where applicable, prepare a supporting Fault Detection and Location analysis to supply data needed for valid decision logic processing.

6 Retain those RCM-related programs applicable to armored equipment that demonstrate success in meeting the primary objective of RCM.

7 Continue the acquisition and improve dissemination of accurate, dependable and useful field operating and maintenance data to provide a solid, provable basis for future maintenance planning.

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EXHIBIT VI

U.S. ARMY RESERVE UNIT, ASMA-49

SURVEY REPORT

SUMMARY

A survey of the U.S. Army Reserve Unit, AMSA-49A was conducted to provide an overview of their maintenance activities and determine the extent of the application of RCM principles to UH-1H and OH58 helicopter and RU-80 fixed wing aircraft. A complete RCM program is not being implemented, but the RCM related activities in their current maintenance program include phased maintenance, oil analysis, and on-condition maintenance. They are also employing other maintenance techniques which have potential RCM application, i.e., health indicator tests for testing turbine engines, N1-CAD battery temperature indicators, and use of a Vibrex machine for tuning rotor hubs.

The capability for understanding and manipulating RCM decision logic was reflected by the maintenance personnel interviewed. These traits, and their familiarity with the true maintenance environment indicate good potential for a mix of maintenance and materiel readiness command engineering personnel making effective application of RCM logic to fielded equipment maintenance programs.

The overall capability of the maintenance personnel, all of whom are Department of the Army civilians, exceeds that of their organizational maintenance counterparts in active Army units. The mechanics have more years of maintenance experience and they are not burdened with military duties in addition to normal maintenance responsibilities.

AD-A063 559 MARTIN MARIETTA AEROSPACE ORLANDO FLA F/G 5/1

RELIABILITY CENTERED MAINTENANCE STUDY.(U)

SEP 78 R TIPTON, R BOEMLER, J ROBINSON DAAG39-77-C-0169

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EXHIBIT VI

U.S. ARMY RESERVE UNIT, ASMA-49

SURVEY REPORT

1.0 BACKGROUND

1.1 Purpose of Survey

This survey was conducted to review the unit maintenance activities and determine whether RCM principles were being applied to helicopters and fixed wing aircraft.

1.2 Organizations Surveyed

U.S. Army Reserve Unit, ASMA-49A
McCoy Air Force Base, Orlando, Florida

1.3 Date of Survey

13 February 1978

1.4 Persons Contacted

Mr. R. Anderson, maintenance mechanic
Mr. J. Barrington, maintenance mechanic
Mr. R. Kokes, maintenance mechanic
Mr. J. Malkemus, maintenance mechanic
Mr. G. Taylor, maintenance mechanic
Mr. N. Waltbillig, maintenance mechanic

2.0 OBJECTIVES AND SCOPE

The U.S. Army Reserve (USAR) Unit, AMSA-49A, was surveyed on-location at McCoy Air Force Base in Orlando, Florida, in conjunction with contract DAAG-39-77-C-0169, Assessment of the U.S. Army Implementation of Reliability Centered Maintenance (RCM). The contract was let to the Orlando Division of the Martin Marietta Aerospace Company.

The objectives of the survey were to:

1 gain knowledge of the maintenance program being implemented, and

2 determine whether RCM and related maintenance disciplines have been applied to helicopters and fixed wing aircraft.

The review encompassed the organizational maintenance that was being performed in support of a total of 41 aircraft: 27 home based, and 14 from Patrick Air Force Base located in Cocoa Beach, Florida. The home based aircraft are comprised of six UH-1H and four OH58 helicopters, and seventeen RU-80 fixed wing type. Seventeen on-line mechanics and ten shop personnel support these aircraft.

An informal discussion was held with the maintenance personnel. The unit's discussion group was headed up by the maintenance supervisor, Mr. G. Taylor. All personnel are Department of the Army civilians (DAC's), under cognizance of Major Burnette, Regular Army (RA). The highlights of the discussion included:

1 an overview of the unit maintenance activities including application of RCM principles

2 application of RCM decision logic

3 manpower utilization and capability.

3.0 MAINTENANCE ACTIVITIES

Although the maintenance personnel were totally unfamiliar with the specific designation of RCM, they have been engaged in a number of closely related formal maintenance disciplines, including phased maintenance, oil analysis, and on-condition maintenance. In addition, other maintenance techniques being employed within the unit were identified as health indicator tests (HIT's) on turbine engines, temperature indicators on N1-CAD batteries, and tuning of rotor hubs utilizing a Vibrex machine.

3.1 Phased Maintenance

The Phased Maintenance Program has been in effect for approximately one and one-half years. The general feeling, even with the institution of Phased Maintenance, is that aircraft are still being over-maintained, thus inducing failures, e.g., breaking screws, damaging panels, etc. On the other hand a few items require more frequent maintenance inspection intervals due to geographic location (sand, salt water, etc.). The maintenance personnel have detected excessive wear in certain bearings because of salt water corrosion.

The Phased Maintenance inspections include daily checks in addition to scheduled inspections performed at 25 and 100 hour intervals. A complete cycle of inspections requires 800 hours. Since the average annual utilization rate for all aircraft at this location is approximately 150 hours, the calendar time for a full cycle requires in excess of five years. Consequently, an assessment of program effectiveness cannot be made at this time.

3.2 Oil Analysis

The Oil Analysis program has been in force approximately five years at this facility. The laboratories at McDill Air Force Base in Tampa, Florida perform the analysis on the oil samples. Engine specimens are taken every 12 1/2 hours and other component specimens every 25 hours of flight time. When additional samples, based on laboratory analysis, are required, or when laboratory personnel have specific changeout recommendations, telephone contact is made with the maintenance unit. The unit is responsive to laboratory recommendations. The number of sample types vary between three and five, depending upon aircraft model.

3.3 On-Condition Maintenance

Inspections are performed annually on every aircraft at the facility by Troop Support and Aviation Materiel Readiness Command (TSARCOM) personnel, in compliance with the On-Condition Maintenance program. The feeling of the maintenance personnel is that questionable criteria exist for overhaul candidate determinations. The aircraft most in need is not always selected for overhaul. In one instance a candidate had accumulated only 30 to 40 hours flight time when selected for return to depot for overhaul.

3.4 Additional Maintenance Techniques

Several other test and inspection techniques that are being implemented were identified during the discussion. An engine HIT is utilized to check turbine engine operation. A baseline reading is established for ambient temperature versus engine exhaust temperature at a specific torque. A rise ("spike") in exhaust temperature is an indication of impending failure of an engine component. After validation of the spike is made a diagnostic routine must be used to identify the deteriorating component.

A battery temperature indicator has been installed on several of the Nl-CAD batteries. A temperature rise accompanies a failed condition. The maintenance personnel feel that condition monitoring of battery temperature is a valid replacement candidate for the seven day battery test, which requires approximately one-half hour to perform.

The Vibrex machine is an extremely useful device that facilitates the tuning of rotor hubs and detection of impeding failures. The unit personnel have, on occasion, borrowed this item from the Air Force and they feel it is both an accurate and time saving device. The Army is contemplating the addition of the Vibrex to the organizational maintenance resources.

4.0 RCM DECISION LOGIC APPLICATION

The decision logic designed for RCM application was also discussed during the meeting. In general, the unit personnel followed the logic paths without difficulty. During the discussion regarding who should answer the logic questions, i.e., maintenance unit or commodity command level personnel, some interesting points were noted. For example, maintenance record data used for justification of task scheduling often is incomplete and/or misleading. The maintenance unit may perform some inspections or tests that are not reported to the materiel readiness command. In addition, maintenance units on occasion order parts because of breakage during maintenance, hoarding or stock piling, etc. Unless the item being requisitioned is on the intensive management list, there is little valid reliability/maintenance data available to the readiness command. Intensive management items are those that are usually reparable, and/or high dollar value components/assemblies. The unit personnel feel RCM logic application should be made by a mix of maintenance and materiel readiness command engineering personnel.

5.0 MANPOWER UTILIZATION CAPABILITY

The unit has been directed to use a 6:1 maintenance manhour/flying hour ratio in calculating manpower requirements for their RU-80 aircraft. They were also directed to use 151 hours/manmonth availability, based on a utilization rate of 92 percent. It was felt this rate was too high and realistically should be approximately 70 percent. The utilization rate of mechanics at RA facilities was quoted to approximate 30 percent.

The general feeling of the personnel in the unit is that their skill capabilities equal or exceed those of mechanics in active Army organizational maintenance units. They have more practical experience and are not laden with military obligations in addition to maintenance responsibilities. It was also noted that components received from direct support units reflect inferior workmanship standards. This results in a feeling of frustration on the part of the mechanics at this facility.

6.0 CONCLUSIONS

The following conclusions result from the review of the USAR Unit, AMSA-49:

1 RCM as an entity has not been applied at this organizational maintenance unit. However, RCM related activities have been implemented.

2 Maintenance techniques are being employed that have potential for inclusion in scheduled maintenance programs, e.g., HITs on turbine engines, use of temperature indicators on N1-CAD batteries, and use of the Vibrex machine to tune rotor hubs and detect incipient failures.

3 Credibility of maintenance data emanating from maintenance support units is questionable. Supply requisitions are often misleading due to the ordering of parts because of maintenance induced failures and stockpiling. In addition, some deviations from formal scheduled maintenance programs are not reported to higher command levels. The problem of maintenance data accuracy is wide-spread and is of concern to other services.

4 The application of RCM logic to fielded equipment may be served best through a mix of maintenance and readiness command engineering personnel. Maintenance personnel are aware of the actual equipment environment and can accurately relate to valid field problems. Their inputs can be of benefit in the formulation of an RCM based scheduled maintenance program. The Communications and Electronics Materiel Readiness Command, for example, has made use of personnel field experience in revision of the preventive maintenance checks and services table for one of their equipment items by including red team survey recommendations in the revised table.

EXHIBIT VII

COMMERCIAL AIRLINES SURVEY REPORT

EXHIBIT VII

COMMERCIAL AIRLINES SURVEY REPORT

Summary

Maintenance programs for new commercial aircraft are developed in accordance with Federal Aviation Administration (FAA) orders. They are the product of a collective effort by the manufacturer, the airline customer, and the Federal Aviation Administration. MSG-2 philosophy is used in the development of the maintenance program.

The airlines are obligated to perform maintenance in accordance with the program for a period of one year of aircraft operation. After that period they have the prerogative of changing the program to suit their individual needs. However, any changes must be approved by the FAA. In effecting changes to the maintenance program some airlines use the MSG-2 concept, while others find that either this philosophy does not satisfy their needs or it proves too costly for their operation. Most changes to the maintenance program are made to increasing the maintenance interval or to upgrade the maintenance program.

To implement an MSG maintenance program, the airline must be willing to pay the price to institute a failure mode analysis program and a data collection and analysis program, as a minimum.

Although the same airlines have implemented MSG maintenance programs for a number of years, it is somewhat difficult to identify the actual cost reductions which can be contributed to the MSG concept.

EXHIBIT VII

COMMERCIAL AIRLINES SURVEY

1.0 BACKGROUND

1.1 Purpose of Survey

To review commercial airlines applications of MSG-2 in developing scheduled maintenance programs.

1.2 Organizations Surveyed

1 Frontier Airlines, Denver, Colorado

2 United Airlines, San Francisco, California

3 Flying Tiger Lines, Los Angeles, California

4 Eastern Airlines, Miami, Florida.

1.3 Dates of Survey

1 Frontier Airlines - 13 November 1978

2 United Airlines - 14 November 1978

3 Flying Tiger Lines - 15 November 1978

4 Eastern Airlines - 22 March 1978.

1.4 Persons Contacted

Frontier Airlines

Mr. Bud Naylor
Vice President, Maintenance

Mr. Joe Shallcross
Manager, Production Control

United Airlines

Mr. Stanley Nowlan
Director, Maintenance Analysis

Mr. Howard Heap
Manager, Maintenance Engineering

Flying Tiger Lines

Mr. Dave Gallegos
Director, Maintenance Administration

Mr. E. B. Hale
Manager, Reliability

Eastern Airlines

Mr. Pierce Hammon
Manager, Maintenance Standard Engineering

2.0 OBJECTIVE AND SCOPE

The survey was performed in accordance with the requirements established in Task 2.0, subparagraph b, of DA contract DAAG-39-77-C-0169, to examine commercial airlines applications of MSG-2 in developing scheduled maintenance programs. The airlines MSG-2 experiences provided a background for evaluating the Army's implementation of its Reliability Centered Maintenance program.

The survey was conducted in visits to four major air carriers. Each airline was selected for some unique reason: i.e. Frontier Airlines, because of the environmental impact of its route structure on maintenance requirements; United Airlines, because United personnel were in the forefront of creating the MSG-1 and MSG-2 maintenance concepts; Flying Tiger Lines, for its unique type of operations; and Eastern Airlines, because it had been reported that they discontinued using MSG-2.

The survey was informal, consisting entirely of conversations with airline personnel most closely associated with the application of MSG-2. Airline policies and procedures pertaining to MSG-2 application were discussed, along with the results experienced. This not only provided information useful in evaluating the Army's RCM program, but also provided information which could be applied to the advantage of the Army's RCM program.

3.0 MSG-2 APPLICATION

Maintenance programs for new aircraft are developed by the aircraft manufacturer in conjunction with representatives of customer airlines and the Federal Aviation Administration. These maintenance programs are prepared in accordance with the instructions and restrictions contained in FAA order 8310.4, "Maintenance Certification Procedures." This document is considered as "The Book" for certification of various aviation-related activities.

The result of this cooperative effort is the issuance of a Maintenance Review Board (MRB) document which contains a maintenance program for each new aircraft type. MSG-2 methodology is used in the development of the MRB document, which is binding on the airlines for one year of operation of the

new aircraft. After a year, airlines may modify their maintenance programs to meet individual requirements, but only with approval of the Federal Aviation Administration.

MRB documents establish maintenance tasks (and required intervals) which are generally referred to as "A", "B", "C" and "D" checks. "A" check intervals usually are initially established at 50 hours with "B", "C", and "D" checks occuring at 250, 2,000, and 20,000 hours, respectively. The "A", "B" and "C" checks are regularly performed until the aircraft approaches 20,000 hours, at which time it is overhauled. After overhaul, the maintenance cycle is repeated.

The airlines have developed individual methods of obtaining FAA approval of maintenance procedural and interval changes. These methods, however, must include the steps necessary to maintain safeguards against degradation of safety and reliability standards. Requests for maintenance program changes can be submitted any time after the first year of the original maintenance program has been completed.

4.0 SURVEY FINDINGS

4.1 Frontier Airlines

Frontier operates 52 aircraft split evenly between Boeing 737s and Convair Conversion 580s, under what may be termed "worst case" environmental and operating conditions from the maintenance standpoint because of the route structure. Not only are the natural conditions of the environment in which Frontier operates severe, but the route structure itself requires a 1.16 per hour landing rate, which is harsh on both the aircraft and their power plants.

Frontier's basic maintenance scheme is fairly common throughout the industry. The effectiveness of the scheme, however, is totally dependent on the management of the individual airline. In Frontier's case the goal is safety: according to a recent issue of Forbes magazine, Frontier Airlines was cited as number 1 in safety. Frontier's Time Control Index is contained as attachment #1 for information and examination.

Frontier's maintenance scheme is basically as follows:

1. Once daily each Frontier aircraft receives a "service check," consisting of visual checks of fluid quantities, tire pressure and wear, and lights, and a walkaround inspection of the aircraft.

2. Every 50 hours of flight time, a maintenance A-check is required, which includes all items in the service check plus additional fluid checks, functional checks, and a more detailed visual inspection of the aircraft.

3 At 250 hours of flight time a maintenance B-check is required. This includes all items mentioned in previous checks, with added requirements for limited-access door and engine cowling removal.

4 At 2,000 hours of flight time a maintenance C-check is required. It requires extensive access door and cowling removal, plus aircraft servicing and functional checks. The entire aircraft is inspected for existing or potential defects by specially qualified inspectors.

5 As the aircraft approaches 20,000 hours it is removed from service for overhaul. For example, a Boeing 737 with 19,445 hours was recently routed to Frontier for overhaul, which was begun on April 15. The aircraft was returned to scheduled flight on May 19. In this case a management team had planned the overhaul activities well in advance of April 15. When overhaul was completed in May some 20,973 manhours had been expended, of which 2,039 hours were devoted to inspection, 16,407 hours to overhaul tasks, and 2,267 hours for cleaning.

Messrs. Shallcross and Naylor were familiar with both the MSG-1 and 2 schemes since they had participated in early decisions reached by the Industry-Government Maintenance Review Board. Frontier found insufficient reason to incorporate the pure MSG-2 scheme into its maintenance program.

4.2 United Airlines

Mr. Stanley Nowlan and Mr. Howard Heap, United Airlines Maintenance Engineering, were among those in the forefront in the creation of the MSG-1 and -2 maintenance concepts. In addition they were co-authors of a manuscript which was written as a DoD "cook book" for applying reliability centered maintenance to complex Army equipment. The book describes a logical discipline that can be used to develop efficient maintenance programs, and ways of managing such programs once they have been established.

United Airlines, the nation's largest airlines, makes extensive use of the MSG-2 concept in performing maintenance planning. United's large engineering staff and data processing capability provide the resources necessary to implement MSG-2. United Airlines probably has the most extensive data base and data processing capability of any airlines.

Failure consequences are the leading parameters for establishing maintenance tasks. Each task in the scheduled maintenance program is generated by an evaluation of the failure consequences, followed by an examination of the explicit relationship between the task and the equipment's reliability characteristics to determine whether the task is either essential, from the safety aspect, or desirable, from a cost benefit standpoint.

The dependance on reliability characteristics results in maintenance programs that are governed by the design characteristics of the equipment; the consequences of the failure likely to be experienced; the techniques available for preventive maintenance; and the information available to conduct program analyses.

The resulting programs identify the minimum amount of work that must be done to realize the inherent safety and reliability characteristics of the equipment. Less work would result in a deterioration of safety and reliability. More work would simply increase support costs without increasing safety and reliability.

United applies the MSG-2 philosophy to its avionics equipment. However, little is to be gained in this area since most avionics failures are instantaneous - that is, without degradation.

In relation to cost benefit analysis, Messrs. Nowlan and Heap both noted that although the implementation of MSG-2 has resulted in a marked reduction of scheduled maintenance (chiefly because the maintenance analysis identified and deleted tasks that were unnecessary or ineffective) actual cost reductions are difficult to identify. This is due in part to the fact that it requires a number of years for the airlines to move from traditional scheduled maintenance concepts to the MSG-2 philosophy. In addition, maintenance programs have changed continually during these years, and each change has cost effectiveness consequences. Thus, there is no marked change in existing maintenance cost records to mark the advent of the MSG-2 philosophy.

4.3 Flying Tiger Line

Flying Tiger Line (FTL), operating 17 DC-8s and 6 Boeing 747s, provides world-wide charter and cargo service. These operations are covered by the same Federal Air Regulations as scheduled passenger-carrying airlines.

FTL maintenance management personnel are well versed in both MSG-1 and -2 but consider the scheme impractical from a cost standpoint. They have instead developed an FAA-approved maintenance program unique to their operational requirements which provides maximum return on investment.

FTL Management feels that due to their fleet size, the technical manpower costs required to support an MSG-type program would not give a good return on investment, since specifically,

1 a failure mode analysis program is required

2 processes for inspecting installed parts must be devised, and

3 a data collection and analysis program must be developed and implemented.

4.4 Eastern Airlines

When Eastern Airlines obtains a new type aircraft it initiates the maintenance program as required by the Maintenance Review Board Document. In the meantime they will prepare an Eastern procedures manual containing the steps necessary to change the MRB requirements, while maintaining proper safeguards to ensure that safety and reliability will not be degraded. This procedures manual is submitted to the FAA for approval. Once the manual has been approved the airline need not obtain FAA approval for changing their maintenance program beyond the initial maintenance program change which under all circumstances must always be approved by the FAA. Thus, if Eastern Airlines in its initial maintenance program change wanted to extend its "C" check from 1200 hours to 1600 hours maintenance personnel would collect data from a sample number of aircraft to document that the 1200 hour limit could be extended safely. This justification would be presented to the FAA along with a request for approval of the change. Once approved, Eastern could extend the time of the "C" checks to 1600 hours. With approval of their change request and procedures manual Eastern would not be required to obtain FAA approval to make subsequent changes to the MRB. Changes to the maintenance program usually serve to increase the maintenance interval or to improve the maintenance program. When Eastern wants to make a change to the maintenance program or to investigate a possible problem area, it collects data on a sampling basis to estimate the nature and extent of the problem. Eastern Airlines does not feel it is necessary to check every aircraft.

When planning a change to the maintenance program, the MSG-2 philosophy is always applied. The decision logic used to determine the category of maintenance however may not necessarily be identical to that prescribed by MSG-2, and may differ from item to item depending upon the type of item and its usage. It was interesting to note that on the A 300 B Aircraft (AIRBUS), they upgraded the European Airlines/manufacturers required maintenance interval based on the results of a single series of A, B, B2 and C checks performed on one aircraft. The application of MSG-2 philosophy has been used in numerous cases to shift from on conditions (OC) removal and bench test to conditioning monitoring (CM). Eastern has no formal documentation system that tracks MSG-2 logic decisions.

Responsibility for initiating changes to the maintenance program has been shifted from engineering to maintenance. All potential changes are funnelled through a technical/judicial committee. The technical side of the committee is made up of engineering and maintenance personnel, while the judicial side consists of manager and director level personnel. Approval of this joint committee is necessary before a change in the maintenance program can be made.

Eastern's basic maintenance policy concerning aircraft engines is that no hardtime maintenance will be performed. When an engine problem is suspected they will borescope and/or use isotope X-ray to identify the problem. Engines with internal problems are removed and sent to the jet shop for repair; external problems are corrected on the aircraft.

Eastern Airlines is engaged in an oil analysis program. However, it performs oil analysis only on a sample basis and only when they suspect a problem. It operates its own oil analysis laboratory for both internal use and use of other airlines under maintenance contracts to Eastern.

Eastern's real-time data collection scheme works as follows: Engine performance data is collected on each aircraft at cruise altitude on a daily basis. This data is provided by the flight crew and is presented in sequence by the position of the engine on the aircraft. Airframe data is collected on a sample basis whenever a problem is suspected. If no problem is suspected or no non-scheduled maintenance is performed then there is no data collection required and the records indicate only the completion of A, B, B2 or C maintenance activities. All data is collected in accordance with the Airline Transport Association coding system. Data collected will be used to alert maintenance personnel to the existence of a problem or potential problem, which is then investigated and changes made if necessary.

One of the most interesting remarks made by Mr. Hammond concerned the cost benefit of changes. He stated that Eastern has not found a good way to quantify the costs benefits resulting from the incorporation of maintenance program changes.

The Eastern fleet has 244 aircraft which are supported by 68 professional engineers.

5.0 ASSESSMENT AND RECOMMENDATIONS

The degree of implementation of MSG-2 among the airlines varies markedly, depending primarily on the operatinal concept and airline size.

Maintenance program changes are made primarily for two reasons: 1) to increase the maintenance interval and 2) to improve the maintenance program.

The airlines do not have an effective way to measure the actual cost benefit derived from the implementation of MSG inspired maintenance program changes.

There is little to be gained by the Army from an analysis of individual airlines' implementation of MSG-2. This is due in a large part to the fact that the airlines operational and maintenance philosophies differ markedly from those of the Army. Except for the basic concept, the airline industry's implementation of MSG-2 has little in common with the Army's implementation of RCM on non-aeronautical products.

EXHIBIT VIII

NAVY RCM SURVEY REPORT

SUMMARY

This survey was conducted at three Naval facilities - Naval Air Rework Facility, Jacksonville, Florida; Naval Aviation Integrated Logistic Center, Patuxent, Maryland; and Naval Sea Systems Command, Arlington, Virginia.

The purpose of the study was to review and analyze Navy programs where MSG-2 and reliability centered maintenance (RCM) principles were implemented. This included the Analytical Maintenance Program (AMP), the Navy's title for its RCM program for aircraft, and Maintenance System Development Program (MSDP), a program for implementing RCM on nonaeronautical equipment.

The visits provided an understanding of the Navy's approach to satisfy the DoD requirement for implementation of RCM on both aeronautical and non-aeronautical equipment.

In the development of these programs, the Navy has used the MSG-2 approach extensively. Engineering analysis and the decision logic process have been implemented to individually analyze and justify each maintenance requirement.

Key elements of the Navy RCM program are:

1 Emphasis on failure mode and effects analysis

2 Use of personnel with a detailed knowledge of systems and equipment for developing the RCM program

3 Consideration of the sustaining engineering phase as being the most important aspect of the program.

Early results from the application of AMP to aircraft has resulted in a significant reduction in maintenance requirements. The MSDP is in the earliest stages of program development.

The Army should consider adapting the key points of the Navy's approach to the application of RCM as standards for developing and implementing RCM on various Army systems/equipment.

An Inter-Service Liaison should be established between the Army and Navy's NAVSEAS/SCOM, as a continual exchange of experiences would benefit both parties.

EXHIBIT VIII

NAVY RCM SURVEY REPORT

1.0 BACKGROUND

1.1 Purpose of Survey

The purpose of this survey was to assess the Navy implementation of reliability centered maintenance (RCM) for the purpose of comparing the Navy's RCM activities to those of the Army.

1.2 Organizations Surveyed

Naval Air Rework Facility (NARF)
Jacksonville, Florida

Naval Aviation Integrated Logistic Support Center (NAILSC)
Naval Air Test Center
Patuxent, Maryland

Naval Sea Systems Command (NAVSEASYSCOM)
Arlington, Virginia

1.3 Date of Survey

NARF - 19 October 1977
NAILSC - 21 October 1977
NAVSEASYSCOM - 30 March and 14 April 1978

1.4 Persons Contacted

Lt. A. J. Blake
NARF

Lt. James Irwin
NAILSC

Mr. Gale Jones
NAILSC

Mr. Kenneth Kelley
NAILSC

Mr. J. M. Pritchard
NAVSEASYSCOM

Lt. Cmdr. Dennis R. Oldson
NAVSEASYSCOM

Capt. Donald B. Stuart
NAVSEASYSCOM

2.0 OBJECTIVES AND SCOPE

The survey was performed in accordance with the requirements established in Task 2.0, subparagraph b. of DA contract (Reference 1). The objective of the program was to review and analyze Navy programs where MSG-2 and reliability centered maintenance (RCM) principles were implemented. These programs were examined to determine the methods the Navy has been using to satisfy the DoD requirement for the implementation of RCM on aeronautical and nonaeronautical systems and equipment. This knowledge has been utilized as a yardstick in assessing the Army's implementation of RCM.

The survey was conducted at three Naval facilities, two of which are concerned with Naval aviation maintenance and the other with shipboard maintenance.

3.0 RCM APPLICATION

To survey the Navy's implementation of RCM, two programs were studied to compare the Navy's RCM principles with the Army. The Analytical Maintenance Program (AMP) for aircraft and the Maintenance System Development Program for ships were reviewed in this effort.

4.0 RCM RELATED PROGRAMS

4.1 Analytical Maintenance Program (AMP)

The Navy's Analytical Maintenance Program (AMP) for aircraft was implemented in 1973 with its application to the Lockheed P-3 aircraft. The program was applied to the S-3, F-4, and A-7 aircraft and J-52, J-60, and J-79 engines shortly afterwards. Today most Naval aircraft and engines now in the fleet have already been the subject of the AMP or are undergoing analysis. Implementation of AMP on all Naval aircraft and engines is scheduled to be completed in fiscal year 1979.

The Navy document governing aircraft and engine maintenance is the Naval Aviation Maintenance Program Manual. It is implemented on specific equipment through a document called a Maintenance Plan which is normally produced during the product development phase of system acquisistion. An individual plan, the heart of which is the Analytical Maintenance Program based on MSG-2, is developed for each functional system. Aircraft MPA Handbook AS-4310, dated 15 January 1975, defines the procedures for Maintenance Plan Analysis for new aircraft.

For those Naval aircraft and engines that have been in service, the Navy developed a Maintenance Plan Analysis Guide (Reference 2) containing instructions for applying the Analytical Maintenance Program in accordance with the principles of MSG-2.

The goal of the analysis process, as defined in Reference 2, is to provide organizational focus and systematic procedures to accomplish the following:

1 Analyze the schedule maintenance requirements for each type and model of aircraft and engines

2 Objectively justify every maintenance requirement

3 Enforce the performance of only the justified maintenance actions at each of the following:

a Depot, where a system undergoes major overhaul and complete rebuilding of parts and assemblies of end items

b Intermediate, the direct support activity for the using unit

c Organizational, where a component can be removed and replaced or repaired within the squadron

4 Develop an optimum balance between the three maintenance levels.

Development of a maintenance program using the principles of MSG-2 requires four basic steps. First is the identification of all potentially repairable and inspectionable system components. These are know as maintenance significant items (MSI). Second step is to perform a failure mode and effects analysis of each MSI. Step three is to develop rate curves for the failure modes of each MSI, from which removal and repair schedules may be determined. The final step is to apply the data to the decision logic diagram and logically determine the maintenance requirements.

Data on equipment usage, schedule maintenance requirements and potential requirements, failure causes, support equipment, and economic level of repair for each maintenance significant item are all factored into the analysis for developing the maintenance program.

Full implementation of Analytical Maintenance Program also addressed the sustaining engineering phase which is considered key to a successful maintenance program. This includes the establishment of analysis centers to assure maintenance program continuity and timely response to fleet problems. The sustaining engineering phase is a continuing effort dedicated to the improvement of operational readiness. Specific responsibilities of the center include:

1 Collecting and evaluating various types of input data such as operational performance data, fleet reliability data, scheduled maintenance results, and other related data

2 Identifying faulty system and/or equipment and isolating the key problem causes

3 Updating significant item lists and FEMA based on reports

4 Revising the procedures to insure optimum aircraft readiness and the most efficient maintenance programs.

The early results obtained from the first aircraft to be completely subjected to the Analytical Maintenance Program using the MSG-2 type logical decision process shows significant benefits. The application P-3 AMP resulted in substantial reduction in scheduled maintenance manhours per flight hour. A 21 percent reduction in P-3 maintenance at both organizational and intermediate levels and a 15 percent reduction at the depot level were obtained. A significant increase in operational readiness and a substantial increase in prescribed depot rework interval resulted. P-3 goes into the depot every 5 years instead of the previous 3-year cycle.

NAVAIR in August 1975 published the Maintenance Plan Analysis Guide for In-Service Naval Aircraft (Reference 2). This guide contains the procedures along with complete instructions to enable the implementation of the RCM maintenance concept for the three levels of maintenance on any aircraft. The procedures identify the methodology necessary to determine those technically justified tasks, along with those tasks that are to be performed because of the economic value they produce.

Application of the procedures contained in the guide will result in a preventive maintenance program containing the minimum number of tasks that must be done to maximize the aircraft availability without degrading levels of safety and reliability inherent in the design.

Within the guide is contained a series of worksheets that provide a convenient form for compiling, organizing, and analyzing the input data to obtain standardized and uniform data for application to the decision logic and for recording the results of the logic application.

4.2 Maintenance System Development Program

In 1976 the Secretary of Defense directed that RCM should be expanded to cover all military vehicles. In compliance with this directive the Chief of Naval Operations issued CNO Objective No. 3 which directed attention to the material condition of ships in the fleet. This in turn resulted in the Ship Support Improvement Project (SSIP), under the direction of NAVSEASYSCOM (PMS-306), which is a long term initiative of CNO Objective No. 3. As part of the SSIP effort, the Navy awarded a contract to American Mangement Systems Incorporated (AMS) to perform extended studies, particularly of the Navy organization for maintenance of ships and ship support delivery systems and provide baseline information for the project. The Lockheed California Company (LCC) was awarded a subcontract by AMS to develop a methodology, based on RCM concepts, for determining the scheduled maintenance requirements of surface ships. The FF-1052 class ship was designated as the model for the analysis and later demonstrations.

In March 1978 the Lockheed California Company provided a manual (Reference 4) to the Navy which contained RCM adaptation procedures for the use of RCM principles in shipboard scheduled maintenance. These procedures involved the application of the necessary decision logic, performance of maintenance task analysis, and maintenance program development. Mathematical models are currently being developed to support the work on the logic, methodology, and analysis requirements.

A prototype demonstration is scheduled to be conducted in 1978 to provide the feedback information to continue the development process of the RCM adaptation procedures. The development of these procedures is an evolutionary process which is effected by the problems facing the Navy in maintaining their ships within the constraints of reduced funding, resource and asset limitations, available manpower and skills, and operational deployment.

Special objectives of the Ship Support Improvement Project include:

1 Defining a logic which adapts RCM principles to a warship

2 Developing a methodology which applies the logic

3 Accomplishing and documenting required analyses in accordance with the methodology

4 Producing a draft set of FF-1052 Maintenance Requirements Cards (MRC) and PMS Schedules

5 Producing a procedure for developing a shipboard scheduled maintenance program derived from defined program logic and procedures

6 Planning and executing a prototype demonstration of procedures in 1978 on board a ship of the FF-1052 class

7 Assisting in preparing for and initiating a practical evaluation of procedures in 1978 on board ships of the FF-1052 class.

The basic plan of this effort was to review RCM principles and their application to aircraft maintenance procedures. A study of the FF-1052 class ship and its current maintenance plan (Planned Maintenance Subsystem) was conducted. The objective was to utilize RCM principles in the development of a method for determining shipboard scheduled maintenance and application of the method to actual FF-1052 systems. Step-by-step procedures include:

1 Review of applicable data and literature

2 Development of a maintenance-oriented library

3 Establishment of a working liaison with various Navy fleet and shore command echelons

4 Review of RCM principles and development of program logic

5 Development of analysis procedures to apply the program logic

6 Initial application of logic and analyses to a FF-1052 class ship.

The procedures, following an at-sea test and final adjustment, will enable a scheduled maintenance program to be developed for the organizational level of any U.S. Navy surface ship. The procedures will identify the methodology required to determine only technically justified tasks placed in a practical and logical sequence and their cost benefit assessment as determined by the analysis process. Application of these procedures is expected to identify the minimum amount of preventive maintenance work that must be done on board ship to maximize its availability. Levels of safety and reliability inherent in design of ship system and structure will not be degraded.

5.0 ASSESSMENT AND RECOMMENDATIONS

5.1 Analytical Maintenance Program

The Navy Analytical Maintenance Program Orientation Handbook (Reference 3) is similar to the Air Force's reference book. Both books provide excellent material for understanding the purpose of RCM as well as the approach used in its application and the benefits to be obtained.

The Navy has implemented RCM on all in-service aircraft and engines, in accordance with Management Manual Maintenance Plan Analysis guide for In-Service Naval Aircraft. Development of the program for the A-7 aircraft had several false starts. These were mainly due to lack of data and the attempt to develop the program at too low a hardware level. In many cases the system and subsystem level hardware should be applied to the decision logic, along with the maintenance significant items (components).

Another problem encountered on the A-7 program was that most of the failure mode and effects analysis performed by the aircraft manufacturer had to be discarded. The reason for this was that these analyses were based on theoretical data generated at the time of the aircraft design and not on real world data. Any RCM program for existing systems and equipment should be based on data collection during actual operations and maintenance. If real world data are not available then the theoretical data should be recomputed incorporating the real world experience.

After the RCM Program was implemented on the A-7, one of the problems that resulted was how to confine the maintenance effort to only those items which were authorized at any given interval. The mechanics were inclined to perform more tasks than were authorized. This has been particularly

true at the depot level where, in the past, the mechanics have performed extensive rework each time the aircraft were brought in.

Nine key elements of the Navy's approach to the application of RCM to its aircraft are as follows:

1 The importance of the failure mode and effects analysis as the heart of RCM was stressed.

2 The Navy's approach is in three phases - analytical phase, implementation phase and sustaining engineering phase.

3 Sustaining engineering is considered the most important phase.

4 Decision logic should tell the hardware needs.

5 The analytical phase must be accomplished by personnel with detailed knowledge of the system.

6 The generic failures mode or engineering failure mode should be arranged by functional failure modes in applying the decision logic.

For example,

No output (functional failure mode)

a Sheared shaft	
b Seized bearing	Generic/engineering failures
c Restriction	

7 Consistency of the application of the decision logic between engineers is most important.

8 Maximum consideration must be given the contents of maintenance records when developing programs for existing system.

9 Prior to beginning the development of a program for existing system, it is most important for the engineer to contact the operational and maintenance personnel at all levels.

Prior to implementation of RCM on in-service aircraft, two levels of training were provided to the units concerned. One training course was structured for the maintenance personnel and the other was for the management personnel. These courses went a long way in gaining acceptance of RCM by the using units.

5.2 Maintenance System Development Program

In development of the RCM program for the FF-1052 class ship under the Maintenance System Development Program, considerable problems have been encountered as the result of the Navy not purchasing MIL-SPEC documentation for the critical components of the ship.

NAVSEA personnel have pointed out that they share a common problem with the Air Force and Army, in that DoD guidance has been inadequate to accomplish the RCM implementation task.

5.3 Recommendations

The Army would do well to adapt and incorporate the key elements of the Navy's RCM program into their own RCM program. The elements are fundamental to the development of a comprehensive RCM program.

The Army should follow the Navy policy of issuing instructions and guideline manuals early in the program. Such manuals provide the basis for uniformity among commands and personnel within the commands.

REFERENCES

1. DA Contract DAAG-39-77-C-0169, dated 23 August 1977.

2. Maintenance Plan Analysis Guide for In-Service Naval Aircraft NAVAIR 00-25-400, 1 August 1975.

3. Navy Analytical Maintenance Program Orientation Handbook.

4. Analysis Methodology Procedures Manual for Development of Scheduled Maintenance Program LR 28313, 3 March 1978.

EXHIBIT IX

AIR FORCE RCM SURVEY REPORT

SUMMARY

This survey was conducted at three Air Force installations - Headquarters, Air Force Logistics Command, Wright Patterson Air Force Base, Dayton, Ohio; Sacramento Air Force Logistic Center, McCellan Air Force Base, Sacramento, California; and Warner Robbins Air Force Logistics Center, Robins Air Force Base, Warner Robins, Georgia. The purpose of the survey was to review and analyze Air Force programs where MSG-2/Reliability Centered Maintenance principles have been implemented.

The visits provided an understanding of the Air Force approach to satisfy the DoD requirement for implementation of RCM on aircraft, and a familiarization of plans for implementing RCM on communication/electronic/-meteorological (CEM) and aircraft support equipment (SE).

The Air Force approach draws heavily on the MSG-2 methodology which utilizes engineering analysis and the logic decision process to analyze and justify each maintenance task.

The method used by the Air Force in the application of RCM is the same as that contained in MSG-2, although the detailed procedures do vary. The decision logic is modified from MSG-2 in that its application to Air Force aircraft takes into account military considerations. In most instances the Air Force has contracted with the prime air frame and engine manufacturer to perform the engineering analysis and apply the decision logic in establishing the RCM program for their products.

Studies have been conducted and plans have been made to expand the application of RCM to include CEM and aircraft support equipment. The initial study indicated that the returns on applying RCM to aircraft support equipment may be minimal.

The Air Force has developed a Benefit Assessment Program Plan to assess the benefits accrued from the application of RCM. Warner Robins Air Force Logistics Center was tasked to select the C-141 as a test case and proceed with the assessment plan preparation and an Air Force-wide evaluation. The assessment plan does not addresss the impact on maintenance manpower or materials and contains no instruction for converting any impact to dollars for computing cost savings.

The Army should establish an Inter-Service Liaison with Sacramento Air Force Logistics Center to keep abreast of the Air Force's story concerning communications/electronic/meteorological (CEM) and aircraft support equipment (SE). The outcome of this study may provide significant data on the cost effectiveness of applying RCM to simple equipment.

Since the majority of the Air Force's RCM effort to date has concerned aircraft structures and power plants it is of little consequence to the Army's application of RCM to non-aeronautical systems/equipment.

EXHIBIT IX

AIR FORCE RCM SURVEY REPORT

1.0 BACKGROUND

1.1 Purpose of Survey

The purpose of this survey was to assess Air Force implementation of reliability centered maintenance (RCM) and methodology of performing cost benefit analysis for the purpose of comparing Air Force RCM activities to those of the Army.

1.2 Organization Surveyed

Headquarters Air Force Logistics Command (HQ AFLC)
Wright Patterson Air Force Base
Dayton, Ohio

Sacramento Air Force Logistics Center (SM-ALC)
McClellan Air Force Base
Sacramento, California

Warner Robins Air Force Logistics Center (WR-ALC)
Robins Air Force Base
Warner Robins, Georgia

1.3 Date of Survey

HQ AFLC - 12 April 1978
SM-ALC - 12 June 1978
WR-ALC - 28 June 1978

1.4 Persons Contacted

Headquarters, Air Force Logistics Command

Mr. Robert L. Fishback
AFLC-LOLM

Major Louis M. Samuels
AFLC, LOLMF

Sacramento Air Force Logistics Center

Capt. Gary Davinger
SM-ALC, MMMM

Warner Robins Air Force Logistics Center

Mr. James Louis
WR-ALC, MMSH

Mr. Geoff Engles
WR-ALC, MMSRAA

2.0 OBJECTIVE AND SCOPE

Review and analysis of the Air Force's implementation of RCM was conducted in accordance with the requirement of Task 2.0, subparagraph (b) of DA contract (Reference 1). The objective of the survey was to gather information to aid in assessing the Army's implementation of RCM. The methods the Air Force used to satisfy the DoD requirement for the implementation of RCM on aeronautical and nonaeronautical equipment has served as a means of comparison in assessing the Army's RCM implementation. Also, the information gathered has been screened for significant items to aid the Army in their approach to RCM implementation.

The survey was conducted at three Air Force facilities; Headquarters, Air Force Logistics Command, Sacramento Air Force Logistics Center, and Warner Robins Air Force Logistics Center. At headquarters, AFLC, the Air Force's overall approach to RCM implementation was the topic of discussion. This included a review of the program status and future plans. The discussion at SM-ALC centered around the application of the airline MSG-2 technique to communications/electronics/meteorological (CEM) and aircraft support equipment (SE). At WR-ALC the recently completed C-141 assessment plan was discussed, along with its application in determining cost benefits derived from changes to the maintenance program as the result of the RCM application.

3.0 RCM APPLICATION

3.1 Present RCM Program

The Air Force implementation of RCM began with the application of Maintenance Posture Improvement Program (MPIP) to the B-52 airframe in fiscal year 1975. Other aircraft structures were brought into the program in fiscal year 1976, and RCM was implemented on aircraft engines beginning in fiscal year 1977. Table IX-1 shows the Air Force RCM implementation schedule from fiscal year 1975 through fiscal year 1981. During this time RCM should be fully implemented on all aircraft structures and engines, missiles, aircraft support equipment and communications/electronics/-meteorological equipment.

All RCM programs implemented to date are comprehensive in scope and consist of system and component function and failure analysis and the use of decision logic to determine the maintenance requirement for each maintenance significant item.

System and component analysis results in identifying systems and their significant items; functions, failure modes, and effects; scheduled maintenance tasks which have potential effectiveness relative to control of operational reliability and safety; and assessment of the potential value of scheduling those tasks having a high probability of restoring the inherent design level of reliability and safety.

When component failure does not reduce flight reliability or safety, the decision as to whether a maintenance task is desirable is based on economic factors. Desirability is determined, then, by examining the effective tradeoff between cost and the benefit of the maintenance task. This analysis provides information for final judgement as to whether identified tasks are worth including in the maintenance program.

Initial Air Force implementation of RCM encompassed the establishment of standard procedures and worksheets for conducting analyses, preparation of guidelines to ensure standard and complete analyses, and instructions for dealing with economic justifications. Implementation directives also addressed aircraft verification and a sustaining phase including the establishment of RCM analysis centers. Specific responsibilities of the centers now include:

1 Collecting and evaluating various types of input data such as operational performance data, field reliability data, field scheduled maintenance results, depot level maintenance results, and aircraft design changes.

2 Adding or deleting from the baseline scheduled maintenance program those items for which evaluation shows a change in reliability characteristics.

3 Updating significant item lists and FMEA, based on reliability reports.

4 Recommending program changes where applicable.

5 Distributing to item and system managers the status, change, and justification of update programs.

6 Other functions as determined by the controlling authority.

A computer program labeled SMFOP has been developed to aid reliability analysis centers in tracking and evaluating component condition. SMFOP stands for Scheduled Maintenance Frequency Optimization Program and is a

mechanized exception report-type computer program designed to aid maintenance managers in keeping inspection programs updated to reflect aircraft inspection needs. The program will (1) identify equipments that are not being inspected but should be, (2) identify failure modes that should be added to the inspection requirements, (3) identify inspections that should be deleted, (4) identify inspection interval changes for discrete tasks, and (5) identify interval changes for computer packages. Warner Robins Air Force Logistics Center is presently planning to use SMFOP for the C-130 and C-141 aircraft.

In many instances of RCM implementation, the Air Force has contracted with prime airframe and engine manufacturers to perform the analysis and establish the RCM maintenance program for their products. In other cases, the Air Force is studying and evaluating the results of the Navy's analysis to determine if the resultant program meets Air Force requirements.

Air Force Logistics Command in September 1977 published pamphlet 66-35, "Scheduled Maintenance Requirements Analysis" (Reference 4). This pamphlet prescribes the analysis techniques to be used in establishing and verifying aircraft maintenance requirements prescribed in AFR 66-14 (Reference 5). Included in the pamphlet are the procedures for developing and maintaining the preventive maintenance program for aircraft. The maintenance requirements analysis program contained therein is designed to implement the RCM strategy.

Although the detailed procedures vary, the basic concept contained in the pamphlet is the same as MSG-2. The decision logic has been modified from MSG-2 to take military considerations into account in its application to Air Force aircraft. Forms for assembling the data and recording the results are included in the pamphlet.

All aircraft maintenance programs initiated after the date of the pamphlet will be in accordance with the requirements contained therein. This includes updating maintenance programs for existing equipment as well as developing maintenance programs for new equipment.

Military Specification MIL-M-5096D was revised as of September, 1977, to include the prescribed techniques and elements of an RCM program, including the decision logic.

The Air Force published an RCM Program Orientation Reference Book (Reference 6) which contains all topics presented in the orientation course, assembled in order of presentation. The book is intended to be used as a refresher course reference book.

The Air Force reference book is similar to the Naval Air Systems Command Analytical Maintenance Program Orientation reference book. Both books provide excellent material for understanding the purpose of RCM, as well as its application, approach, and benefits to be obtained.

3.2 Typical RCM Results

Application of RCM to the B-52 has impacted the maintenance processes as follows:

1 RCM reduced the number of base level maintenance tasks from 1,263 to 903, a reduction of 360 tasks.

2 The number of depot level maintenance tasks was reduced from 688 to 604, a reduction of 84 tasks.

3 The number of hardtime tasks was 25 for the base level and 10 for the depot level prior to the application of RCM. After application of RCM, the number of tasks was reduced from 10 to 7 at the depot level. At the base level, however, the number of hardtime task remained the same.

4 On-condition tasks numbered 97 for the base level and 158 for the depot level prior to the application of RCM. After RCM application the numbers were reduced from 97 to 72 at the base level; but were increased at the depot level from 158 to 169.

5 Prior to the application of RCM the condition monitoring tasks numbered 1141 at the base level and 806 at the depot level. After application of RCM, these tasks were reduced from 1141 to 520 at the base level, and from 806 to 428 at the depot level.

The T-38 aircraft was th e su ject of an RCM analysis completed for the Air Force in August, 1977, by Vought. The conclusions drawn from this analysis (Reference 3) were presented at the T-38A RCM conference in October, 1977, and are:

1 No part of the weapon system can be ignored during analysis.

2 Equipment users must be part of the decision-making team from the outset of the program.

3 All decisions must be fully documented and justified.

4 A test program should be implemented to verify predicted cost and time savings.

5 Analysis procedures must be standardized.

6 Analysis forms provide comprehensive justification documentation.

3.3 Future RCM Programs

Air Force plans for RCM implementation on their missiles, aircraft support equipment (SE), electronic countermeasures (ECM) equipment, and communications/electronics/meteorological (CEM) equipment began in fiscal year 1978. The Minuteman Missile is exempt from the RCM since it is condition-monitored constantly while on station. The Air Force is giving serious consideration to excluding aircraft support equipment from the RCM program.

A producibility, reliability, availability, and maintainability (PRAM) project has been approved for a three-phase program to apply RCM to CEM and SE equipment. Under Phase I, CEM/SE data systems and maintenance organizations would be surveyed, and methodology developed under the MPIP would be studied for further adaptation to suit these equipments, data, and organizations. Under Phase II a set of representative CEM/SE would be selected for trial application of the newly developed methodology and the criteria for selecting analysis candidates would be developed. If trial applications under Phase II demonstrate adequate return on the investment for the Air Force, Phase III would provide for application of RCM to all qualified CEM/SE across the inventory.

A contract for Phase I was completed in April 1978. Results of that effort were presented in a report submitted to SM-ALC, which contained the following conclusions:

1 SE maintenance programs would probably not benefit from an in-depth MSG-2 type analysis for the following reasons:

   a The equipment is simple enough so that its access is not manpower significant.

   b Many items can be and are allowed to run to failure.

   c Most failures are the "wearout" type, therefore existing inspections are adequate. The maintenance effort could be made more effective, however, with improvements in certain areas, e.g. better documentation traceability, and improved communication between the -6 workcard custodian and the -6 user.

2 Many CEM equipment items appear to be potential candidates for systematic MSG-2 type analysis, since many nonproductive and potentially counterproductive preventive maintenance tasks are presently required in scheduled inspections.

3 The MSG-2 logic process developed for aircraft can be restructured and used for determining whether each specific significant item is a candidate for scheduled inspections if condition monitoring can be applied to CEM/SE equipment. Modifications are required to replace certain aircraft-oriented questions (concerning aborts and repair times) with comparable CEM-oriented questions. One other change is the matter of grouping logic questions into two categories - one to determine the necessity of PMI and the other to determine what tasks are to be implemented.

4 The means of identifying significant items and determining their operational consequences will depend on whether the equipment is being developed or is in operation. For equipment in development, existing CDRL items may provide a failure mode and effects analysis (FMEA) and hazards analysis, which are directly applicable to the MSG-2 analysis approach. For systems already deployed and in service, the most effective approach appears to be field surveys to review maintenance requirements. Through a structured questionnaire, the existing requirements can be evaluated against modified MSG-2 criteria.

It was recommended that Phase II effort for CEM/SE be implemented, with the following limitations:

1 Apply the MSG-2 type analysis to CEM equipment only.

2 Select trial equipment from the following list of candidate equipment categories:

a Air/ground UHF/VHF radios

b TRACALS radars

c TRACALS navigational aids

d Weather instruments.

3 Apply newly developed methodology only to operational equipment, starting with the preanalysis (field survey) process in preparing the Significant Item (SI) list and conducting the FMEAs.

4 Assess the adequacy of field survey data analyzing equipment significant failure modes by conducting a formal FMEA.

5 Use information from existing AF maintenance data systems to compare and evaluate the efficiency of new PMIs with that of old PMIs.

6 Develop a method for selecting candidates for the analysis, using selection criteria such as equipment cost, population, mission essentiality, deployment environment, deployment site, and scheduled and unscheduled maintenance costs.

It was also recommended that the Air Force require all new equipment manufacturers to apply MSG-2 type logic when preparing recommended preventive maintenance requirements.

A detailed review and analysis of the report on application of airline MSG-2 analysis techniques to communications/electronics/meteorological and aircraft support equipment is contained in Attachment 1 to this exhibit.

4.0 BENEFIT ASSESSMENT PROGRAM

Using its C-141 aircraft as a test case, the Air Force developed a plan for assessing benefits accrued through the application of RCM. The C-141 RCM program developed by Lockheed Aircraft Corporation, C-141 prime contractor, under contract to Air Force, was implemented in 1977.

The assessment plan was developed in response to an Air Force Audit Agency Report. The plan required Air Force Logistics Management Center program managers to accumulate data and assess the impact of RCM program, exclusive of the manpower determination process. For that, Air Force will continue to use its approved standard method of establishing maintenance personnel requirements. Therefore, by direction the C-141 Benefit Assessment Program Plan (Reference 7) does not address manpower requirements. An additional restriction is that RCM assessment uses only data from in-place data systems. As a result, the majority of available indicators were not designed for RCM assessment. The indicators selected are considered the most likely demonstrators of RCM benefits in operations and maintenance areas, some are more revealing than others. The 19 separate variables following will be screened and evaluated as part of the assessment effort:

1 Aircraft Availability

2 Availability

3 Reliability

4 Abort Rate - Air/Ground

5 Inflight Failures

6 Diversions

7 Accidents - Maint/Material

8 Incidents - Maint/Material

9 Tail Number Swaps

10 Operation Readiness

11 Training Reliability

12 Enroute Reliability

13 Delayed Discrepancies

14 ISO Flow Time Data (Dock Time)

15 Average/Manhours per W fix Action

16 Number of Maintenance Actions

17 Requests for Assistance

18 Remove and Replace Actions

19 Inspection Frequencies

Since the Assessment plan does not address maintenance manpower variances or material consumption, there is little possibility of determining the dollar variables between pre-RCM and RCM maintenance programs. Nothing in the Air Force's RCM Benefit Assessment Plan exists for determining the delta dollar value between the pre-RCM and RCM programs.

6.0 FINDINGS

The Air Force has implemented RCM on its aircraft structure and engines as prescribed in MSG-2, by utilizing engineering analysis and decision logic. RCM implementation has shown steady progress since first being applied to the B-52 in fiscal year 1975. Studies have been conducted and plans have been made to expand RCM from aircraft structure and engine application to electronic counter measure (ECM) communications, electronic, meteorological (CEM) and aircraft support equipment (SE). The Air Force has some reservations about applying RCM to support equipment. The main concern is that the return on investment may not warrant the effort and costs.

The majority of the Air Force's RCM programs have had funds allocated for that purpose and most were developed by the equipment's prime contractor as contract requirements.

Since most of the Air Force effort to date in the area of RCM has concerned aircraft structures and power plants there is little for the Army to draw upon. The Air Force is just beginning to be concerned about application of RCM to nonaeronautical equipment. In fact, the initial study in this area has only recently been completed. It may prove to be to the Army's advantage to monitor the Air Force progress in the application of RCM on communications/electronics/meteorological and aircraft support equipment for some significant development.

The Air Force's Benefit Assessment Program to assess the benefits accrued from the implementation of RCM offers very little for the Army as this program is aircraft orientated and does not appear to be adaptable to other equipment.

REFERENCES

1 DA Contract DAAG-39-77-C-0169, 23 August 1977.

2 AFM 66-1, "Maintenance Management."

3 Minutes of T-38A RCM Conference - 25 October through 3 November 1977.

4 AFLC Pamphlet 66-35, "Scheduled Maintenance Requirements Analysis."

5 AFR 66-14, "Equipment Maintenance Policies, Objectives, and Responsibilities."

6 "RCM Program Orientation Reference Book."

7 Benefit Assessment Program Plan, C-141 System, May 1978.

ATTACHMENT

1.0 INTRODUCTION

ARINC Research Corporation published a report in April 1978 for the Sacramento Air Logistics Center (SMALC), entitled "Application of Airline MSG-2 Analysis Techniques to Communication/Electronics/Meteorological and Aircraft Support Equipmment". This attachment reviews the activities and results of Phase I of a three-phase program plan anticipated by the SMALC. The overall plan will include ground equipment in the Air Force Maintenance Posture Improvement Plan (MPIP) which, up to now, has been applied only to aircraft.

The MPIP was started by the Air Force in 1975 to review and analyze preventive maintenance (PM) programs for aircraft. The MPIP utilizes the principles set forth in the MSG-2 document which was developed as the basis for the scheduled maintenance program for wide bodied airplanes. The procedural analysis techniques of the MPIP have been applied to a number of aircraft including the F-111, FB-111, and T-39.

Portions of PM programs on military aircraft could not be justified when analyzed under the MSG-2 approach. This led to the consideration of applying MPIP to communications/electronics/ meteorological and support equipment (CEM/SE).

A three-phase program was defined to determine the potential for the application of the MSG-2 concept to CEM/SE. Phase I, conducted by the ARINC Research Corporation, included a survey of maintenance organizations and a study of the MPIP methodology for adaption to these equipments, data, and maintenance organizations. Phase II will include a selection of CEM/SE for trial application to the newly developed MPIP methodology and development of the selection criteria for the equipment candidates. Finally Phase II, if deemed to provide adequate return on investment for the Air Force, will include application of the MPIP to all qualified CEM/SE in the inventory.

2.0 STUDY APPROACH

ARINC Research Corporation performed two major tasks within the scope of the Phase I effort: A review of selected maintenance programs and the development of analysis techniques applicable to CEM/SE. The initial task was a survey of Air Force organizations to provide an overview of the following items:

1 Existing maintenance programs for various equipment types

2 Scope and content of scheduled maintenance activities

3 Desirability of formal analysis methodology for various equipment types

4 Guidance in selection criteria for CEM/SE candidates for application of the MSG-2 based maintenance programs

5 Appropriate methods and procedures for documenting maintenance actions

6 Adequacy of data systems to support inspection interval determination.

The second task performed was the structuring of an analysis methodology applicable to CEM/SE, based on the survey data and methodology developed for F-111, FB-111, and T-39 aircraft.

3.0 PHASE I ACTIVITIES

3.1 Field Survey

The field survey included visits to organizations whose activities were concentrated on maintenance of aircraft ground support equipment (AGE) and CEM equipment. Discussions with site personnel related to the following topics:

1 MSG-2 program background and its potential application to CEM/SE

2 Nature of existing programs

3 Scheduled maintenance work packages - general content, peculiar requirements, general adequacy, inspection intervals, improvement suggestions

4 Maintenance documentation and related problems.

3.1.1 AGE Survey

AGE items surveyed included electrical generator sets, lighting units, electrical power carts, hydraulic test stands, tow bars, bomb trailers, and other types of similar equipment. Scheduled maintenance on AGE often includes servicing inspections to provide for replenishment of consumables (fuel, oil, water) and inspection of safety items (brakes, tires, lights, etc.). Periodic inspections are scheduled on a calender basis, adjusted to be in concert with equipment usage, i.e., operating hours per month.

Much of the AGE is critical in nature and therefore makes the scheduled maintenance program a vital element in the overall support program. Malfunctioning munitions handling equipment, for example, can result in extreme safety hazards, damage to aircraft, and loss of mission. Other considerations cited by maintenance supervisors on equipment other than munitions handling equipment hardware include:

1 Critical mission requirements of the Strategic Air Command prohibit operate-to-failure criteria for the equipment.

2 Equipment usually requires extensive rework at the scheduled intervals due to misuse by flight line operators.

3 The AGE maintenance shops are often located a long distance from the flight line and quick exchange of malfunctioning equipment is not possible.

The general conclusion made from the AGE survey is that, other than possible minor improvements to workcard formats. existing scheduled maintenance programs for AGE are effective. Elimination of inspections and/or effective extension of inspection intervals through application of an MSG-2 type analysis appears remote.

3.1.2 CEM Equipment Survey

The CEM equipment surveyed included radar sets, ground radios, teletype units, navigation aids, and crypto equipment. The survey uncovered cases of unnecessary inspection and equipment replacement, both of which cause reduced availability or equipment performance. The need for development and implementation of a systematic method of determining the necessity and content of PM appears to be needed. There appears to be a lack of consistency in requirements from system to system.

A review of the maintenance program on an old vintage precision approach radar set revealed operating line replaceable units (LRUs) are exchanged with spare units and cycled through inspection at least once every 28 days. Examination of workcards revealed questionable inspection requirements. It appears some requirements could be eliminated and/or inspection intervals lengthened without significant impact on equipment performance or availability.

Radio transmitter and receiver equipment appear to be inspected too frequently and for the wrong reasons. Most receivers, for example, are now solid state devices which require very little if any scheduled maintenance. The equipment has very few incipient failure characteristics and little is accomplished by inspection.

Scheduled maintenance of teletype equipment consists chiefly of routine cleaning and lubrication. No significant benefit from application of MSG-2 analysis is apparent.

An interesting observation was made on the differences between CEM equipment and aircraft in their relationships of maintenance to operators. Aircraft are normally in the hands of maintenance personnel, with periodic operations scheduled while CEM is normally in the hands of the operators, with periodic maintenance scheduled. The nature of many CEM equipment operations requires the presence of an organizational maintenance man during system operation. Changes to the scheduled maintenance requirements do not change the requirement for the operators. However, some cost savings might be realized in reducing maintenance-induced failures and replacement of test (but not operationally) identified weaknesses and/or failures, e.g., tube testers are often more demanding than the operational system.

3.1.3 Maintenance Documentation Survey

Air Force Manual 66-1 establishes the requirements for a maintenance data collection system (MDCS) which consists of collecting, sorting, and retrieving of base level maintenance production data. Personnel interviews suggest the data collected contain many inaccuracies, particularly in the maintenance manhour accounting area. The following points may account for a large portion of the inaccuracies:

1. To meet assigned productivity goals, there is a strong tendency to overstate the time required for completing maintenance.

2. There is often improper coding of maintenance actions. For example, investigations revealed that some manhours expended on repair functions (unscheduled) were actually recorded as inspection functions (scheduled), distorting the actual maintenance picture.

The consensus is that the MDCS data is not sufficiently reliable to meet the requirements of an MSG-2 analysis. The data can serve as a useful input; however, it is not reliable enough to be used exclusively to make critical decisions affecting inspection requirements, effectiveness, and intervals and should be supplemented with other information sources.

3.2 Methodology Development

3.2.1 Methodology Modification

The original MSG-2 concept was modified by the MPIP to redirect emphasis toward Air Force aircraft missions. Additional modification to the MPIP methodology was required for applicability to CEM/SE and included the following:

1. Minor changes to the MSG-2 logic

2. Use of a simpler, less costly method than a formal failure mode and effects analysis (FMEA) for deriving the information needed for application of MSG-2 logic to systems and equipment already in operation.

The changes in MSG-2 logic include replacement of the aircraft oriented question concerning aborts and repair time with the question, "Will the function failure/degradation repair cycle exceed the mission downtime requirements?". The only other logic change is a reorganization of the questions into two groups, the first intended to identify the necessity for PM inspections and the second identifying what tasks are to be implemented.

The second modified item is the depth of analysis required to support the structuring of the scheduled maintenance program. An analysis method employing FMEA can be economically obtained from equipment manufacturers through utilization of Contract Data Requirements List (CDRL) items covering the analysis required for the reliability and safety efforts on

development of new systems. For systems already in use, however, the most effective approach for obtaining similar data appears to be through field surveys of a sample of the using organizations. Use of a structured questionnaire existing "-6 workcards", and any organizational (local) requirements can be evaluated against MSG-2 criteria, and the frequency of PM intervals evaluated on the basis of field experience.

3.2.2 Methodology Guidelines

A four step approach has been proposed for the maintenance analysis process to determine scheduled maintenance requirements.

Step 1 - Initial Evaluation

This step applies only to operational equipment. The remaining steps are common to application on newly developed equipment. Step 1 identifies system functional requirements and determines which systems would benefit from an MSG-2 type, in-depth analysis. The analyst must determine if a field survey of user organizations is required to support the equipment analysis effort. A key item in this step is the determination of the adequacy of existing scheduled maintenance requirements. If deemed adequate, the system is not subjected to the MSG-2 process.

Step 2 - SI and FMEA Preparation

This step identifies the hardware to be subjected to an in-depth analysis for both operational and new equipments. It includes preparation of a significant item (SI) list and identification of functions, failure modes, and failure effects for evaluation against MSG-2 type logic questions.

Step 3 - Evaluation of Necessity of Scheduled Tasks

Each failure mode at the system and SI level, identified in Step 2, is processed through the MSG-2 analysis diagram which evaluates the necessity of performing scheduled maintenance tasks. The key factors addressed are safety, hidden functions, repair cycle versus downtime requirements, and backup data for justification of inspection tasks (economics, effectiveness).

Step 4 - Determination of Scheduled Tasks and Intervals

This step identifies scheduled maintenance tasks that have potential for detection and/or prevention of equipment malfunctions, i.e., test/inspection and/or time change replacements. Procedures are also provided when scheduled task intervals must be calculated.

3.3 Maintenance Analysis Forms

Newly developed forms were identified to support the evaluation of maintenance requirements of Air Force CEM/SE.

MA-1 Significant Item Candidate List. A form is completed for each SI candidate. It provides for designation of the item by class: existing task, safety, hidden functions, problem component. Provision is made for recording the disposition of the candidate item, i.e., SI or not an SI.

MA-2 Failure Modes and Effects Analysis. This form is completed for each SI, summarizing the physical attributes of the item and listing the important functions, failure modes, and effects.

MA-3 Maintenance Summary. Historical failure data for each SI is recorded on the form. Source data may be the 66-1 Maintenance Management System or other reliable source. If no data source exists, the form may be omitted. Completed forms are used to complete other maintenance analysis forms, evaluate existing maintenance programs, and support new requirements.

MA-4 Definition of Potentially Effective Tasks. This form is used to record the answers to the MSG-2 logic questions addressed to an SI. It also provides for the recording of task description or justification for no task, as appropriate.

MA-5 Task Interval. Each potential task that is identified will have an acompanying form MA-5, which will show the pertinent factors in the calculation of the task interval.

MA-6 Scheduled Maintenance Task Comparison. This form is only completed on SIs in operational systems. It provides for a comparison between new or revised tasks and the old requirements.

4.0 COMMENTS

The preceeding paragraphs were intended to give a consolidated description of the Phase I effort, as conducted by the ARINC Research Corporation, of the planned three-phase study directed toward expanding the applicability of the MPIP to encompass CEM/SE. The following comments are offered on specific elements of the Phase I effort:

1 The overall approach to the application of the MSG-2 analysis techniques to CEM/SE, as developed during Phase I, appears to be effective. The key elements of an MSG-2 type program have been identified, i.e., development of a SI list, a FMEA or equivalent analysis, development of maintenance task decision logic, procedures for determining task intervals, and forms to be used in evaluating maintenance requirements. The logic used in the MSG-2 analysis process addresses the following questions:

   a Why scheduled maintenance tasks are required, i.e., safety, hidden functions, mission downtime requirements, and economics.

b What maintenance tasks are potentially effective in detecting and/or preventing undesirable system failures.

c The determination of effective time intervals for performing scheduled inspections, tests, or equipment replacements.

2 Much of the SE used by the Air Force is of a critical nature. It is logically anticipated that inspection of many safety/mission critical items are included in scheduled maintenance programs, and inspection intervals are adequate to meet system safety and reliability requirements. Without the opportunity of reviewing these programs, however, it can only be assumed that no benefit would be derived from an in-depth MSG-2 analysis of existing maintenance requirements.

3 The study concludes that the application of MSG-2 analysis to existing CEM equipment would be of benefit in eliminating unnecessary inspections and replacements, extending inspection intervals, and establishing consistency in requirements between systems. However it should be stressed that applicability of MSG-2 to new CEM equipment would, in all likelihood, be very limited. This equipment displays a constant failure rate over much of its expected life and possesses very few, if any, incipient failure traits. Consequently, periodic inspections and time change replacements would not prove beneficial.

4 The inadequacy of the Air Force MDCS is a problem that is common to data collection efforts attempted by the Army. Credibility of maintenance data for both services is suspect due to reporting inaccuracies in manpower expenditure and assignment of maintenance categories. Historical maintenance data are not only used in updating existing equipment support requirements, but in the development of maintenance planning for new systems as well. The establishment and control of improved data collection and reporting methods should be undertaken by the services as priority tasks.

5 The field survey questionnaire, designed for use in the initial evaluation of operational systems (Step 1), may include questions difficult to answer in total by field maintenance personnel. The following questions are examples:

a Question 7 - Identification of failure modes.

b Question 8 - What are the effects of failure modes?

c Question 11 - Does the failure mode exhibit an incipient failure condition?

d Question 12 - What are the symptoms of incipient failures?

e Question 15 - How long would it take for the incipient condition to propagate to failure?

Furthermore, if the questionnaire is intended to address all failure modes and effects for a system, its completion could prove to be a lengthy process.

6 Adequacy of a field survey to support the development of a FMEA for operational systems is questionable. There is little assurance that all critical failure modes and effects will be identified without additional analysis being performed. The risk of omitting items from the MSG-2 analysis process on critical systems would be prohibitive.

7 The description of the activities required for conducting the initial evaluation of operational systems (Step 1) is not sufficiently explicit. For example, question (b) of the maintenance analysis procedure, "Does the -6 workcard contain only those maintenance tasks that are necessary and effective?", is a key question. A yes answer precludes the need for development of a SI list, FMEA, and processing of this data through the MSG-2 logic process. The instructions for development of the maintenance program do not specify the criteria or method to be used in answering this question.

8 The Phase I activities focus on the organizational and intermediate maintenance aspects of CEM/SE. No direct reference was made toward depot maintenance activities. Based on Army experience, review of maintenance requirements at depot level has potential for economic benefit. The scope of the Phase I effort should have been expanded to include a detailed review of depot maintenance programs for CEM/SE.

9 Detailed procedures for the determination of inspection intervals are included in the report. However, no reference is made to determining time change intervals for items whose reliability degrades with age. It would seem appropriate to include separately identifiable procedures for determination of time change replacement intervals.

10 The maintenance analysis forms devised as part of the maintenance program development are adequate. Provisions are made to record the pertinent information related to SIs and include FMEA data, maintenance analysis summary data, replies to MSG-2 logic questions, and task interval data. The forms collectively provide a means for evaluating maintenance requirements for CEM/SE and establish traceability for MSG-2 analysis decisions.

11 An interesting observation is made regarding cost savings. The nature of certain CEM operations necessitates the presence of a maintenance person whenever the system is in operation. Changes in scheduled maintenance requirements, therefore, result in very little change in maintenance manhours, since "you are paying for the person anyway". Cost savings may be realized, however, in the reduction of maintenance induced failures.

A parallel situation exists in attempting to evaluate savings through reliability centered maintenance implementation by the Army. Reduction of operator preventive maintenance checks and services, however extensive, does not eliminate the need for the equipment operator. Therefore, there are no personnel cost savings realized through reduced operator maintenance requirements.

Cost savings through reduction of maintenance induced failures may be realized. Past experience on an Army developmental system included the application of K factors to equipment failure rates. These factors varied inversely with the level of maintenance, e.g., K=4 at organizational level, K=2 at the direct support level, and K=1.4 at the depot/factory level. The K factors assigned may very well vary between systems however. Consequently the determination of the actual cost savngs realized from reduced maintenance activities would be difficult to measure.

EXHIBIT X

ANALYSIS AND EVALUATION

OF

MAVIS MODEL

SUMMARY

The MAVIS model was designed for the purpose of determing the inspection interval for the various systems and equipment contained in manned aircraft. Initially the model was designed for application to the UH-1.

There have been some suggestions that the model contained the essentials for application to Army equipment other than manned aircraft. To determine if there was merit in these suggestions an analysis and evaluation of the MAVIS model was performed utilizing the MAVIS User's Manual dated April 1976, to determine whether the model did contain the essentials for a broad application and if it could be applied in conjunction with the development of reliability centered maintenance programs for a broad range of Army systems/equipment(s).

ANALYSIS AND EVALUATION OF MAVIS (MODEL FOR ANALYSIS OF VEHICLE INSPECTION SYSTEMS)

1.0 SCOPE

MAVIS is a systematized methodology for optimizing vehicle inspection/maintenance schemes, primarily through the determination of phased inspection techniques. MAVIS uses computer modeling of the candidate vehicle inspection/maintenance scheme, but this modeling process comprises only a small portion of the entire methodology. Figure 1 depicts a typical MAVIS application; Figure 2 is an expansion of Step 6 (of Figure 1). Of the 17 steps defined in the application, only two actually involve computer applications. The others are concerned with defining, collecting, and editing the extensive historical data required for the computer phase, or engineering evaluation of the computer output and modification of driving parameters in order to iterate the modeling process. Thus, although MAVIS appears to be primarily a computer application, it is actually a labor-intensive methodology, making use of computer modeling for specific functions.

2.0 APPLICATION

MAVIS, as designed and described in the User's Manual, is applicable to helicopters. However, minor modifications to terminology would permit both methodology and computer phases to be used with any system/equipment compatible with the basic premise and the data requirements of the MAVIS methodology; the system/equipment must exhibit failure modes characterized by the failed item entering a detectably deteriorated state at some measurable interval prior to total failure; extensive R&M data must be available for the system.

3.0 INPUT DATA REQUIREMENTS

One of the primary restrictions to the application of MAVIS to a system/equipment is the requirement for an extensive and comprehensive base of R&D data concerning the system/equipment. The 26 data items listed in Table X-1 must be obtained for each component of the system to be modeled. Additionally the 7 data items shown in Table X-2 must be obtained for each Time Based Overhaul (TBO) item of the system, as must the 5 data items of Table X-3 for each lube item.

Additionally, successful operation of MAVIS requires that the system/equipment under consideration be divided into inspection areas or zones following certain prescribed criteria. (The User's Manual strongly recommends this be accomplished with the assistance of a trained vehicle (Helicopter) inspector and the use of an actual vehicle.)

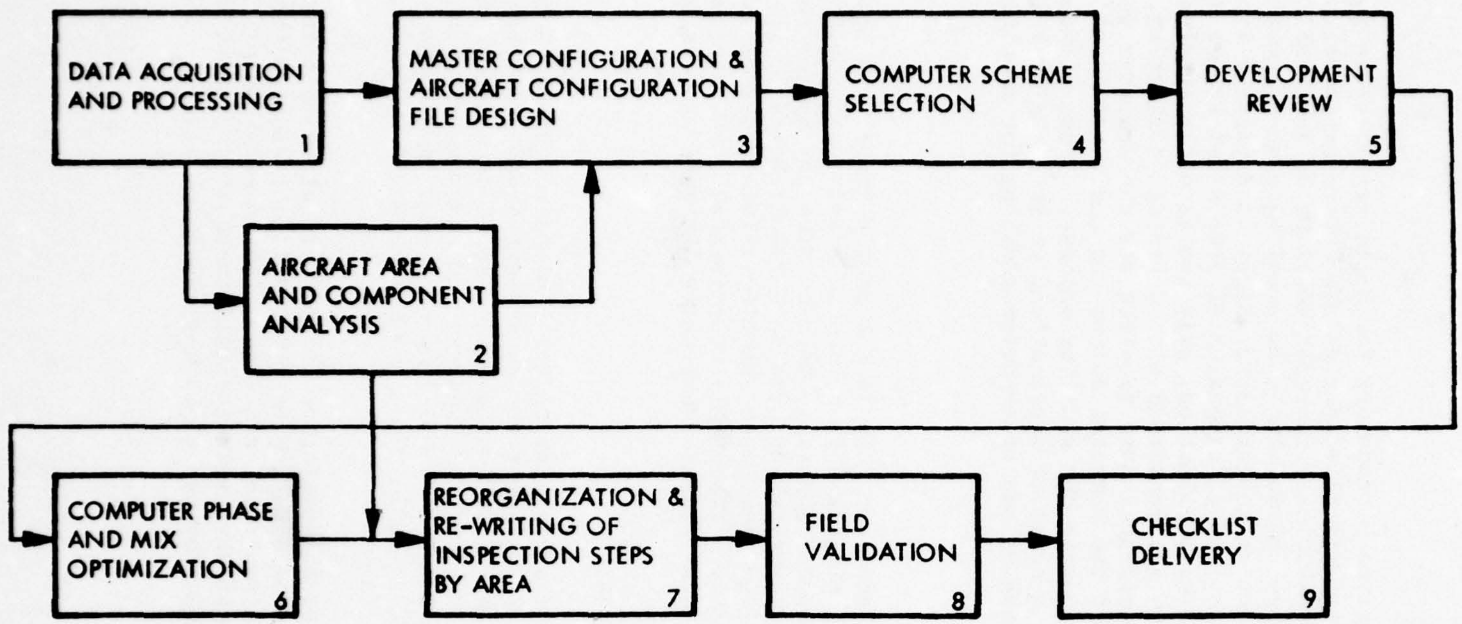

Figure X-1. Typical MAVIS Application Process

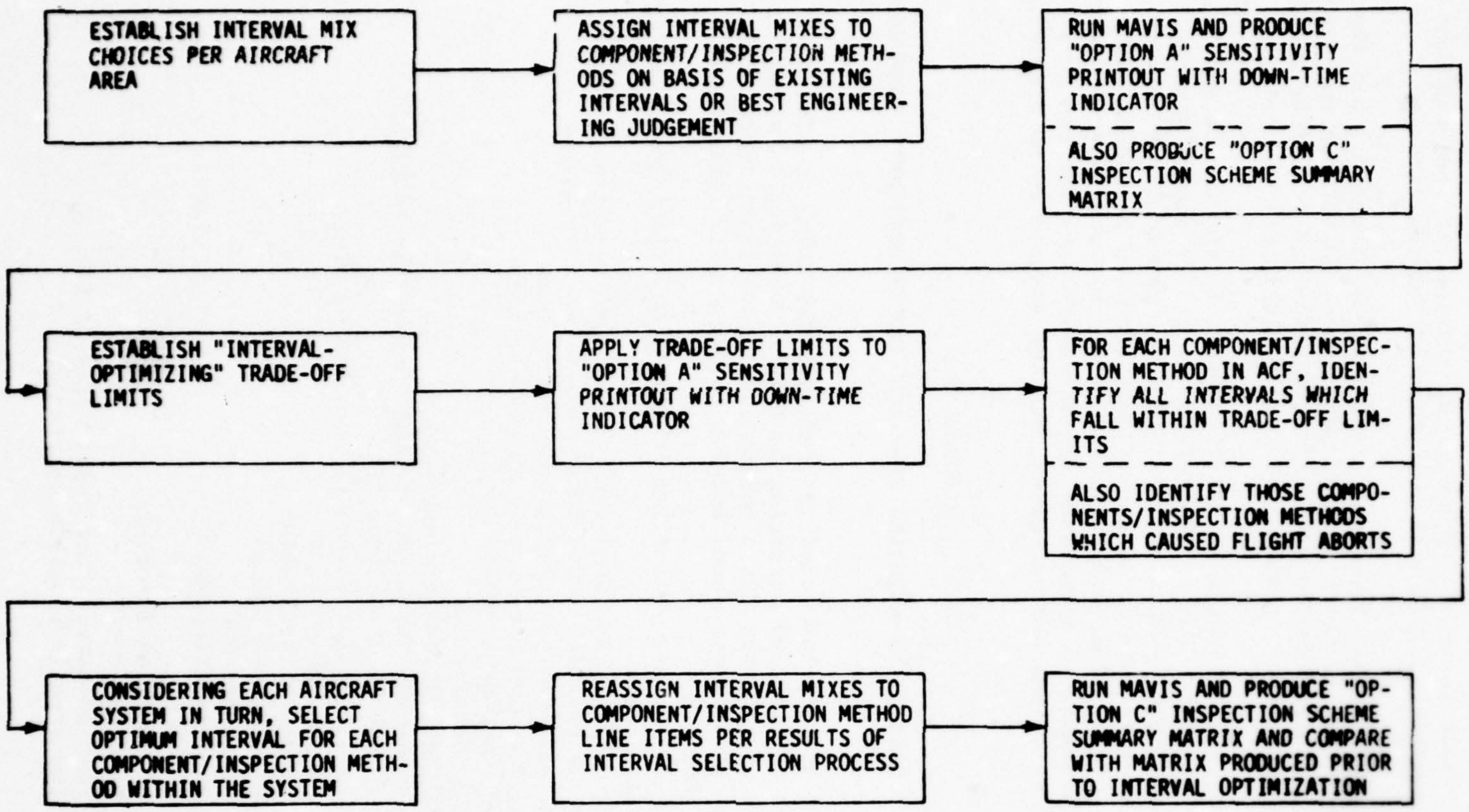

Figure X-2. Inspection Interval Optimization Process

Each run of the computer phase requires that the 8 data items shown in Table IV be input for each component type-inspection area combination in the system/equipment along with the computer control cards.

Not only are these input data requirements extensive, but the particular data form required by MAVIS, in many cases, is not the form in which R&M data is acquired by the military services, thus requiring additional editing and processing of data, prior to MAVIS input.

The initial application of MAVIS, quoted in the User's Manual, was to the UH-1 helicopter. Due to the safety aspects of manned aircraft, much more extensive data is kept on such systems, than would be kept on less safety critical systems (howitzers, tanks, armored personnel carriers, generators, etc.). The User's Manual states that four months elapsed time was required solely to accumulate the necessary data for the UH-1 (manpower figures for this task are not given, but are assumed to be significant).

TABLE X-1

INPUT DATA ITEMS REQUIRED FOR EACH SYSTEM/EQUIPMENT COMPONENT

- MTBF
- Percent of failures found in preflight resulting in mission abort
- Percent of failures occurring in flight resulting in mission abort
- Percent of failures found before flight/preflight inspection
- Percent of failures found between flights/postflight or daily inspection
- Percent of failures occurring in flight or flight test not resulting in mission abort
- Percent of failures found during calendar inspection
- Percent of failures found during all other inspections
- Percent of failures found by all other means
- Number of components of this type in vehicle
- Assigned component number
- Component description
- Failure mode (3 possible entries)
- Flight readiness inspection method (3 possible entries)
- Flight readiness inspection time
- Scheduled inspection method (5 possible entries)
- Scheduled inspection time
- Average elapsed repair time
- Average repair man-hours
- Flight readiness MOS
- Scheduled inspection MOS
- Repair MOS
- Current inspection interval
- Safety critical rating
- Flight test required after repair (Yes or No)
- Inspection area (4 possible entries)

TABLE X-2

INPUT DATA ITEMS REQUIRED FOR EACH SYSTEM/EQUIPMENT

TIME-BASED OVERHAUL ITEM (TBO)

- Assigned component number
- Component description
- Probability of survival from one overhaul to the next overhaul
- Interval in flight-hours between TBO's
- Average elapsed repair time
- Average repair man-hours
- Repair MOS

TABLE X-3

INPUT DATA ITEMS REQUIRED FOR EACH SYSTEM/EQUIPMENT LUBE ITEM

- Assigned component number
- Component description
- Lube interval in flight-hours
- Lube time
- Lube MOS

TABLE X-4

INPUT DATA ITEMS REQUIRED FOR EACH SYSTEM/EQUIPMENT
COMPONENT-AREA COMBINATION FOR EACH COMPUTER PLAN

- Assigned component number
- Component description
- Inspection area in which component is found
- Quantity of this component in above area
- Pre-flight inspection indicator (Yes or No)
- Post-flight inspection indicator (Yes or No)
- Daily Inspection Indicator
- Inspection period and interval (Coded)

It is reasonable to assume equivalent or greater expenditure of time would be needed for the data collection phase if MAVIS were to be applied to other systems/equipment if, indeed, sufficient data is available to satisfy MAVIS requirements.

As an example, the data available on the Pershing Weapon System was investigated. Due to the Unified Data Collection System (UDCS) which has been implemented on the Pershing system for several years and the current Extended Data Collection (EDC) program to accumulate specific maintenance data, there is probably a more extensive base of data available for the Pershing system than for any other military system not involving manned flight.

This investigation showed, however, that even with this extensive data base, approximately twice that needed for MAVIS, the specific data to exercise the current implementation of MAVIS has not been maintained on the Pershing system.

This lack is primarily in those data elements required to determine T_{OS}[1] for items below the end-item level.

Another result of this investigation was a general insight into the basic costs of acquiring sufficient data for MAVIS from a fielded system. The Pershing EDC program utilizes data technicians at one site to monitor activities and encode and record data on three batteries. The annual collection costs for EDC are approximately $300,000 exclusive of data reduction and analysis. Projections of MAVIS data collection costs to accommodate other system/equipment, based on these figures, should consider the number of sites and time span necessary to acquire meaningful data on the candidate system/equipment as well as the comparative amount of data required, which should be proportional to the comparable complexity of the system/equipment to the Pershing system.

4.0 OUTPUTS

The end outputs of MAVIS are revised inspection schedules for the analyzed system. Specific outputs from the computer phase are divided into three categories selectable by control cards at program execution:

1 Option A: Results for each component

2 Option B: Man-hour summary by system or area

3 Option C: Overall summary

The specific information in each output category is as follows:

---

(1) The average time interval between the time deterioration is first detectable and the time failure occurs.

Option A:

For each component in every area, the following is printed out as a calculated rate per 10,000 flight hours:

- a Scheduled repairs
- b Unscheduled repairs
- c Flight readiness inspection manhours
- d Scheduled inspection manhours
- e Scheduled repair manhours
- f Unscheduled repair manhours
- g Scheduled repair maintenance time
- h Unscheduled repair maintenance time
- i Mission aborts
- j Inflight aborts
- k Interval between inspections

Components are listed numerically by WUC (Work Unit Code) number, and subsystem and system totals are also printed.

Option B:

Results are printed out either by system or area for each of the following categories:

- a Scheduled inspection manhours
- b Scheduled repair manhours
- c Scheduled repair elapsed maintenance time

For all the above categories, each area or system is listed followed by all MOS numbers utilized on that area or system and a breakdown of manhours by each MOS for every inspection point within one cycle.

Following the above printouts, a concise summary of all scheduled effective manhours over one inspection cycle is listed, again by either area or system.

Finally, the following values are printed, again over one inspection cycle:

- a Total scheduled actual manhours
- b Total scheduled downtime hours
- c Average inspection crew size
- d Average repair crew size
- e Probability that a flight test will be required after the inspection

Option C:

An overall summary which prints out figures for evaluating several aspects of inspection scheme effectiveness. The results listed, based on 10,000 flight hours, are:

- a Flight reliability = 1 - (in-flight aborts/number of flights)
- b Mission reliability = 1 - (mission aborts/number of flights)
- c Operational readiness = 1 - (downtime/calendar time for 10,000 flight hours)
- d Norm-scheduled = (scheduled downtime/calendar time)
- e Norm-unscheduled = (scheduled downtime/calendar time)
- f MH/FH-flight readiness inspection = (flight readiness inspection manhours/flight hours)
- g MH/FH scheduled-look
- h MH/FH scheduled-fix
- i MH/FH unscheduled maintenance
- j MH/FH total - sum of f, g, h and i.
- k Mean time between unscheduled maintenance actions (unscheduled MTBM).
- l Average utilization
- m Average flight duration

5.0 COMPUTER COMPATIBILITY

The existing MAVIS computer phase is compatible with any IBM 360/370 computer supporting the H Level Fortran IV compiler with only minor JCL (Job Control Language) changes to accommodate installation standards. Operation on other equipment requires the presence of a Fortran IV compiler, and would require completely different JCL and possible modifications to the source code to suit the particular implementation.

6.0 CONCLUSIONS

MAVIS is a comprehensive methodology and computer model for optimizing the inspection scheme of a vehicle, primarily through the implementation of phased inspection. To be utilized properly, the following constraints must be met prior to MAVIS implementation.

1 The candidate system/equipment must exhibit failure modes amendable to detection by periodic inspection prior to total failure.

2 Very extensive and comprehensive R&M data must be available on the candidate system/equipment.

3 Adequate engineering and technical manpower must be available for data collection, preparation, and analysis of the computer phase output.

In the absence of any of the above, the utility of MAVIS is extremely doubtful. Application of MAVIS to other than aircraft systems which meet the above criteria would require changes in definition of certain terms, and, for comprehensive usage, changes in notation in the computer program source code.

The MAVIS model does have application to systems/equipment other than aircraft, however, prior to any application to other than aircraft systems, the agency planning the application should assure that the above listed constraints can be met, particularly those concerned with input data. It is highly unlikely that adequate data for MAVIS is currently available for Army systems of lesser complexity or lower safety requirements than the helicopter systems for which MAVIS was designed. Particular attention must also be paid to proper modification of item definitions and computer notation to suit the planned application.

As for the application of MAVIS as part of RCM program development, it does not lend itself to application to systems/equipment undergoing logistic support analysis as part of the product development. The reason being that the nine basic inputs are derived from usage data which, of course, does not exist at this stage of the product development. It could have application to RCM programs which are being developed for existing systems/equipments, however, it would greatly increase the cost of development and implementing the RCM program for the reasons cited above.

EXHIBIT XI

EVALUATION OF AMCP 750-16

APPENDIX C

SUMMARY

Appendix C (Analysis Guidelines for Determination of the Maintenance Plan Using the Principles of Reliability Centered Maintenance) to AMCP 750-16 (AMC Guide to Logistics Support Analysis) was evaluated to determine its effectiveness in integrating the principles of reliability centered maintenance (RCM) into the logistics support analysis (LSA) process. This Appendix provides guidelines to include RCM in the LSA for the determination of a system/equipment maintenance plan. The activities inherent in LSA effort are well suited to implementation of RCM. Included in the LSA process is a failure mode effects and criticality analysis (FMECA), which provides the identification of critical items and their failure modes. The FMECA data is applied to RCM decision logic for determination of RCM tasks deemed effective in preserving or restoring system/equipment design levels of safety and reliability. The LSA also provides the form necessary for recording the results of an RCM analysis and their impact on logistic support resources.

Appendix C shows the decision logic developed for determining the feasibility and desirability of scheduled maintenance tasks required to support a system and highlight problem areas which require redesign consideration. The decision logic reflected in the Appendix satisfies requirements for determination of an effective scheduled maintenance program. Modifications to the decision logic and other portions of the Appendix are recommended as indicated in paragraph 6.

Overall, Appendix C meets the requirements for establishing guidelines necessary to implement RCM principles maintenance planning. The Appendix includes a detailed description of the decision logic developed for integration of RCM into the LSA process. Its contents also include procedures for determination of RCM tasks and their intervals, instructions for recording the results of the RCM analysis, and examples of decision logic application.

EXHIBIT XI
EVALUATION OF AMCP 750-16, APPENDIX C

1.0 INTRODUCTION

Commercial airline operators and aircraft manufacturers have been able to develop effective scheduled maintenance programs through the use of logic decision processes. In 1968 a maintenance steering group comprised of representatives of various airlines developed handbook Number MSG-1, "Maintenance Evaluation and Program Development," which provided decision logic and procedures for developing a maintenance program for the Boeing 747 airplane. Through updating of the decision logic and deletion of 747 peculiar information, evolved a universal document (Number MSG-2) which is applicable to a variety of newer type airplanes. This document provides the guidance necessary to determine the makeup of an effective scheduled maintenance program for new aircraft.

The Navy has successfully applied the principles outlined in MSG-2 to their program on the P-3 aircraft. The Department of Defense (DoD) has acknowledged the potential success of applying the MSG-2 principles to all military systems and equipment. Consequently, DoD has decreed that the concept of MSG-2 be applied to all new aircraft put into service in fiscal year 1977 and all in-service aircraft and other military equipment by the end of fiscal year 1979. In response to the DoD direction to implement the concept of MSG-2, the Department of the Army (DA) has developed RCM for application to developmental and existing DA equipment. The guidelines included in Appendix C to AMCP 750-16 were developed for application on equipment that is being newly developed.

2.0 SCOPE

The U.S. Army DARCOM, Material Readiness Support Activity has developed guidelines for integration of RCM into the LSA process. These analysis guidelines are published as Appendix C to AMCP 750-16. This report evaluates the integration of RCM procedures into the LSA program as outlined in Appendix C. Documents reviewed in support of this assessment were AMCP 750-16, MIL-STD- 1388-1 (Military Standard, Logistics Support Analysis), and MSG-2 (Airline/Manufacturer Maintenance Program Planning Document).

3.0 BACKGROUND

The concept of MSG-2 recognizes the fact that a maintenance program cannot improve the safety or reliability levels of aircraft. Maintenance programs developed to support an aircraft can only restore safety and reliability to their inherent design levels. If these levels are unsatisfactory, they can only be improved through engineering redesign.

The objective of an efficient airline maintenance program is to prevent deterioration of inherent levels of reliability and safety at minimum cost. The maintenance program is comprised of:

1 Scheduled tasks performed at fixed intervals to prevent/detect deterioration of reliability and safety, and

2 Unscheduled tasks resulting from:

a Discrepancies uncovered in the performance of scheduled tasks

b Failure reporting by operator/crew

c Reports of equipment deterioration resulting from the operator/crew performing normal duties.

The unscheduled tasks are performed to restore equipment to its inherent reliability and safety levels.

Maintenance under the MSG-2 concept falls into one of the following categories:

1 On condition: inspections or tests performed at scheduled intervals to determine deterioration of an item or system.

2 Hard time limit: scheduled replacement of an item at predetermined intervals of age/usage. Items requiring a hard time replacement have either limited life or require periodic overhaul.

3 Condition monitor: unscheduled tasks that are accomplished by means available.

Through application of decision logic, scheduled maintenance tasks judged to be effective in preventing deterioration of reliability and safety levels can be identified and included in the maintenance support program. As a prerequiset to using decision logic, a FMECA must be performed to identify critical failure modes and components. Noncritical items will be included in the scheduled maintenance program only when the life cycle cost (LCC) of the equipment or system is reduced.

4.0 RCM PROGRAM ELEMENTS

The activities essential to formulation of an effective RCM program are:

1 Development of required input data

2 Development of decision logic

3 Application of input data to decision logic

4 Recording of logic decisions

5 Implementation of RCM decisions

6 Sustaining Engineering (Audit Trail and Assessment)

The LSA process, due to its inherent characteristics, is highly adaptable to implementation of the principles of RCM. The decision logic, which RCM provides, is required to determine the scheduled maintenance tasks of on condition and hard time limit and further identifies the requirements applicable to the condition monitor process. LSA provides the input, FMECA, data that must be applied to the decision logic and further provides the means of recording/implementing the results of the logic decision process. Figure XI-1 depicts the integration of RCM into the LSA process.

4.1 Input Data

The data required to input RCM decision logic is comprised of identification of all maintenance significant items and FMECA information for those items. A LSA B sheet is completed for every repairable item of a system or equipment. Recorded on this sheet is the FMECA for each failure mode considered in addition to pertinent maintainability and reliability data. The FMECA data is particulary significant in that it identifies components and functions that are critical in terms of safety and reliability. Critical items are of prime concern in development of the RCM program and are highlighted when processed through the decision logic. In the implementation of RCM into the LSA process, the B sheet has been modified to include the results of the RCM analysis. The revised B sheet provides for the RCM analysis data to be recorded on the B06 card and is depicted in Figure XI-2. The recording of RCM analysis data will be discussed later in this report.

4.2 RCM Decision Logic

The RCM decision logic developed as part of the LSA process is designed to highlight system/equipment components which are critical to safety and mission reliability. It further identifies scheduled maintenance tasks that fall into the on condition and/or hard time replacement category. The basic criteria for the decision logic is to:

1 Schedule maintenance tasks for critical items when effective in preventing safety and reliability deterioration below acceptable levels or when a reduction in LCC can be realized.

2 Schedule maintenance tasks on noncritical items when a reduction in LCC can be realized.

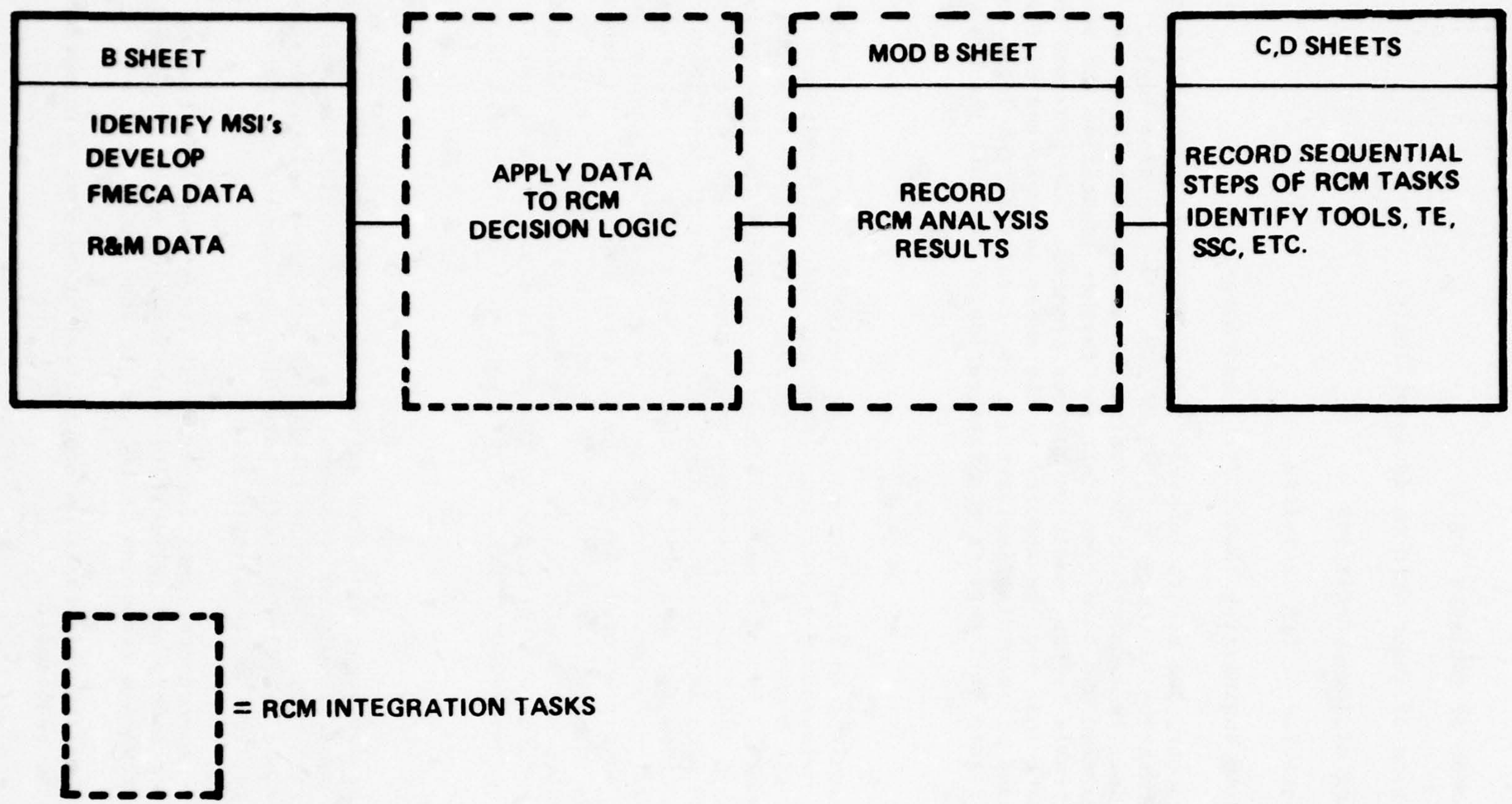

Figure XI-1. RCM/LSA Integration

DATA SHEET B: ITEM RELIABILITY (R) AND MAINTAINABILITY (M) CHARACTERISTICS

ØØ1

ØI3ØIA | XM999 | A | 22255 | A

A | N | H.I.Y | SUB | 77Ø615 | A

TRACK SHOE ASSEMBLY | 1.ØØ | A

78155-1 | 22255 | 78155-1 | 22255 | A

MAINTAINABILITY CONSIDERATIONS

A A A A | A A A A | A A A A | N N N | 3.6ØØØ | 1.Ø | 2ØØ.Ø | A

FAILURE ANALYSIS

Failure Mode 16-31	Failure Symptoms 32-47	Failure Effect and Criticality 48-63	Fail Rate 64-66	Repair Time 67-71	Task Code 72-78	Update Code 80
PAD WEARS, CHUNKS	LOSS OF TRACTION	ROAD DAMAGE	6Ø.Ø	.5Ø	JGOXXAA	A
BUSHING FAILS	DEAD SHOE	LOSS OF POWER	2Ø.Ø	2.ØØ	JGOXXAB	A
SHOE BREAKS	TRACK SEPERATION	LOSS OF MOBILITY	1Ø.Ø	2.ØØ	HGOXXAA	A
PINS SHEAR	TRACK SEPERATION	LOSS OF MOBILITY	1Ø.Ø	2.ØØ	JGOXXAC	A

RELIABILITY CENTERED MAINTENANCE ANALYSIS (APPENDIX C)

Logic Results: Block Number	Disposition (CM / OC / HT / DR)	FGC WBS WUC 34-44	Task Code 45-51	SLN 52-53	Update Code 80
Y	Y	Ø13	AMOXXBA	69	A
Y	Y	Ø13	AMOXXBA	1.Ø	A
Y N N N Y Y					A
Y N N N Y Y	Y				A

ITEM FUNCTION 16-79
PROVIDES TRACTION AT GROUND SURFACE | A

MAINTAINABILITY REQUIREMENTS 16-79
NONE | A

MAINTENANCE CONCEPT 16-79
QUARTERLY VISUAL INSPECTION OF SHOE CONDITION R/R AND REPAIR AT ORG. MAINTENANCE. | A

COST ANALYSIS REQD. TO DETERMINE IF CHANGE IN PIN MATERIEL WILL DECREASE LCC. NEW MATERIEL WILL ENHANCE RELIABILITY OF FAILURE MODE 4. | A

Figure XI-2. Modified LSA B Sheet

The RCM decision logic incorporated into the LSA process is depicted in Figure XI-3. Since the decision logic is the vital element of the RCM implementation process, a discussion of each individual block is included in this evaluation:

Block 1: This block is designed to identify failure modes of a system or equipment that are critical in terms of safety or mission reliability. The questions in this block are answered based on the FMECA data generated for the item. The criticality of the item is essential information that must be determined prior to application of the item to the remaining decision logic. A yes answer out of this block indicates a critical failure mode or component.

Block 2: This block addresses the identical information as in Block 1 for secondary failures that may be induced by the failure mode under consideration. A yes answer in this block indicates a critical secondary failure.

Block 3: Addresses the economical aspects of considering the inclusion of scheduled maintenance tasks on noncritical items in conjunction with those for critical items. A significant point is made in that these items should not be addressed until the scheduled tasks for all critical items have been determined.

Block 4: The key question: "Can the operator/crew detect an impending failure through routine monitoring during normal operations, in time to prevent a safety hazard or misison abort?", is asked in this block. A yes answer indicates a condition monitor is effective in averting a safety hazard or mission abort from developing. The yes path then proceeds further into the decision logic to determine the feasibility of on condition and hard time replacement tasks. If the answer to question 4 is determined to be yes with a high degree of confidence, the yes path should dead end into a condition monitor situation. Determining the feasibility of on condition and hard time replacement tasks beyond a yes answer and then determining the most cost effective maintenance task appears to be academic. Inclusion of an additional task (on condition or hard time replacement) would not appear to be more cost effective than a condition monitor performed in conjunction with normal operator/crew duties. The qualification for a yes answer should be determined for each system/equipment prior to processing through the decision logic. By dead ending the yes output of this block into a condition monitor decision, the ensuing blocks: 5,6,7,13,14,15, and 16 can be eliminated from the decision logic.

Block 5: Identifies candidates for on condition maintenance tasks. This block contains a clear explanation of sound logic for identifying feasible on condition category items.

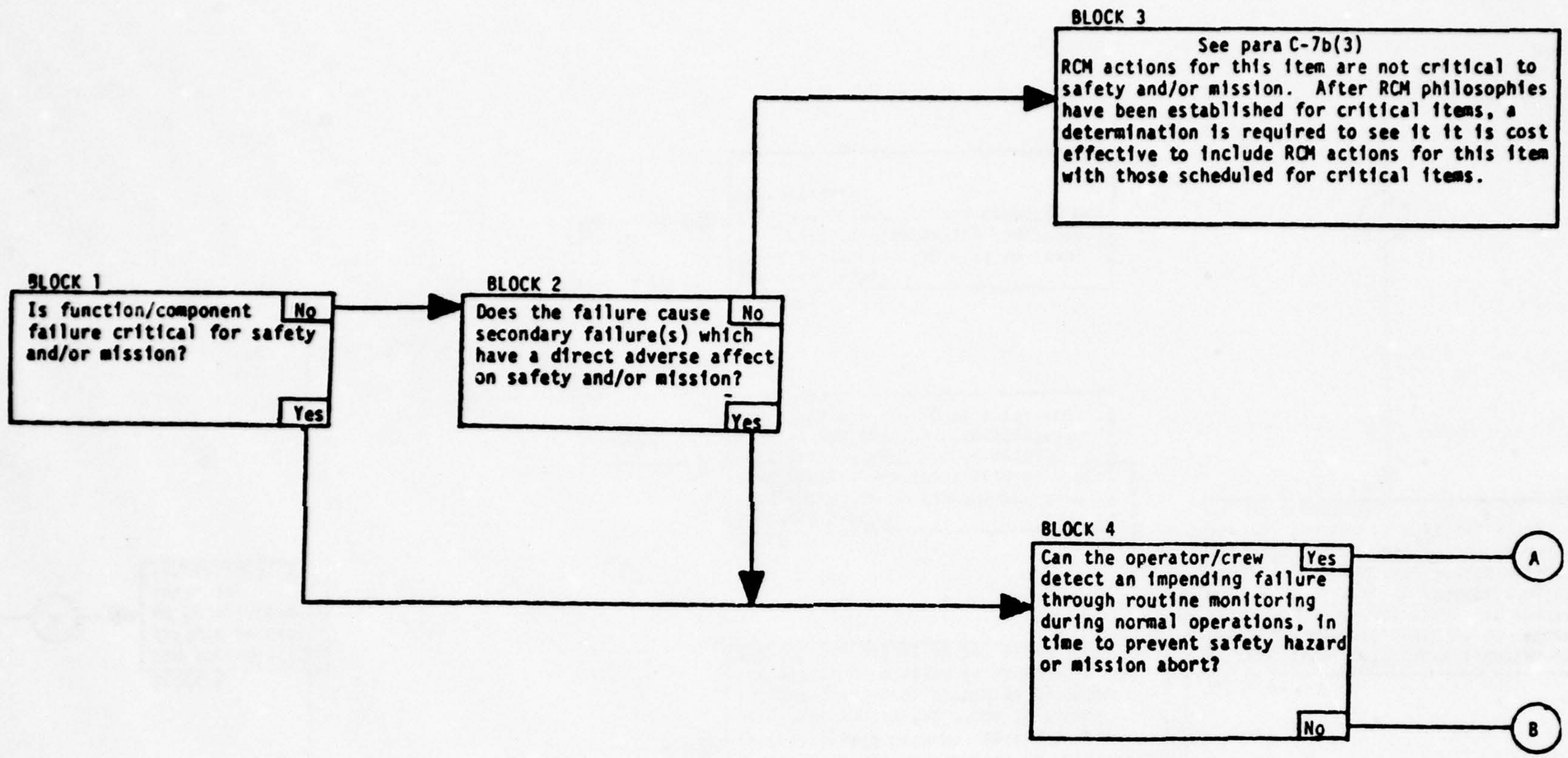

Figure XI-3. RCM Logic (1 of 3)

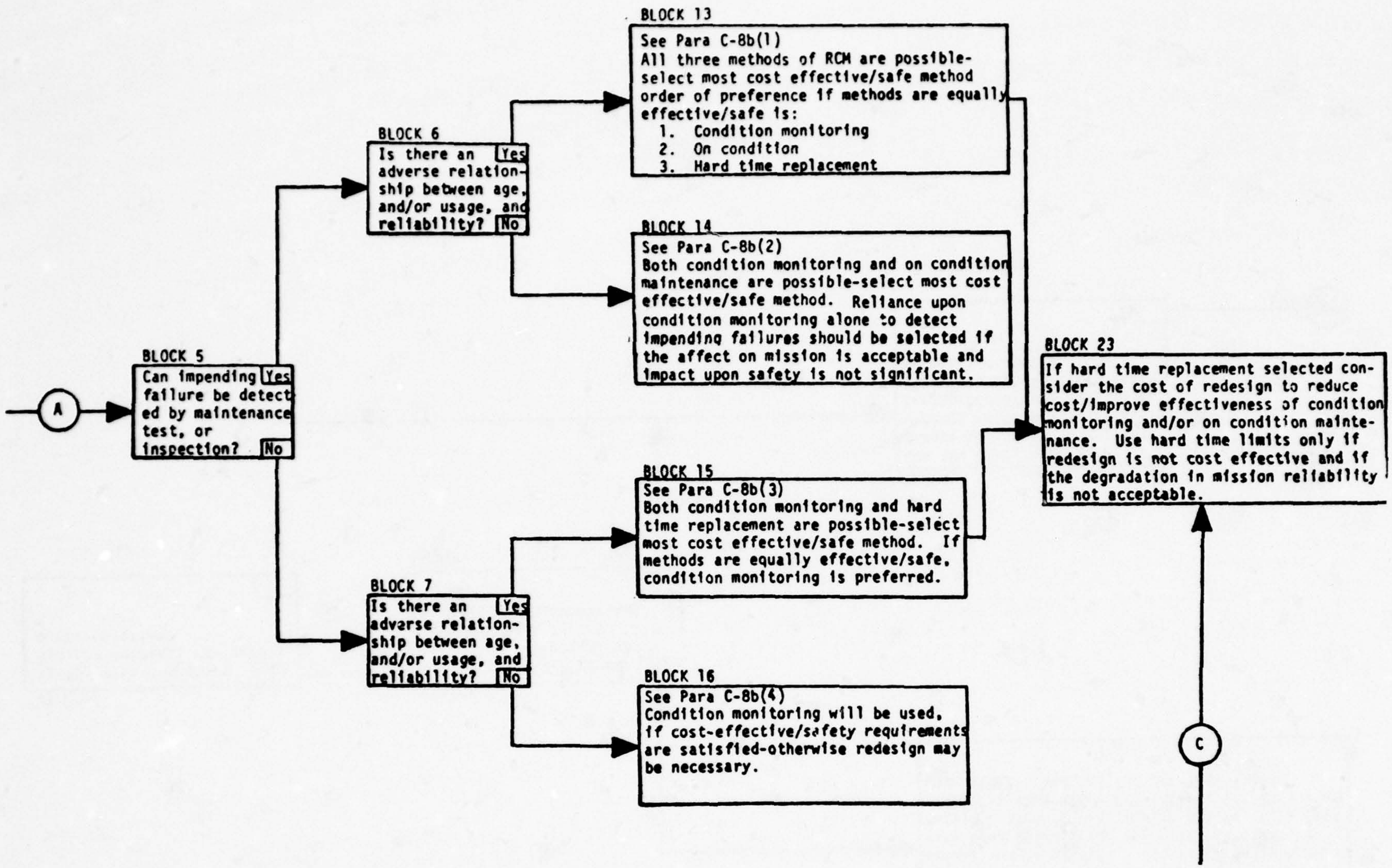

Figure XI-3. RCM Logic (2 of 3)

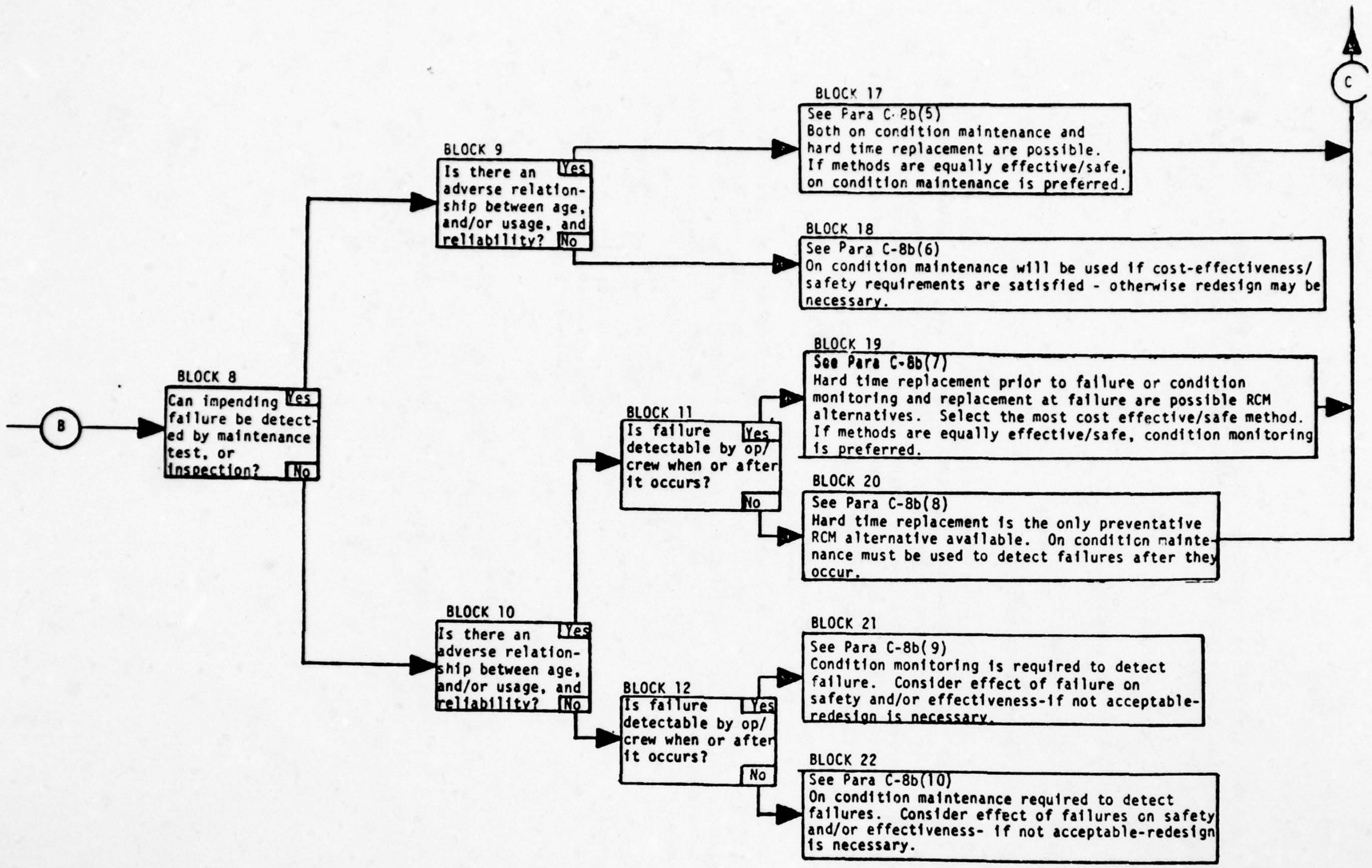

Figure XI-3. RCM Logic (3 or 3)

Block 6: Identifies candidates for hard time limit tasks. This block clearly explains the criteria that must be satisfied for an item to be considered in this category.

Block 7: Same as Block 6.

Block 8: Same as Block 5.

Block 9: Same as Block 6.

Block 10: Same as Block 6.

Block 11: This block identifies hidden functions, i.e.(1) a function which is normally active whenever the system is in use, but where there is no indication to the observer/crew when the function ceases to perform; or, (2) a function whose failure is not apparent until the function is required. If the function is hidden (a "no" answer) then an on condition task is required to determine if failure has occured.

Block 12: Same as Block 11.

Block 13: Reaching this block in the decision path is a result of an item being a candidate for condition monitor, on condition, and hard time replacement tasks. The instructions state that the most cost effective/safe maintenance method should be selected. When the feasibility of each maintenance category is addressed in the logic preceding this block, a yes answer should only be given if the degree of adequacy is sufficient to preserve acceptable levels of reliability and safety. The decision in this block would then become purely economic. It would appear that condition monitor would likely be most cost effective. The comments on this block relate to those on block 4, where a yes answer will usually dead end into a condition monitor decision.

Block 14: Identifies condition monitor and on condition candidates. The comments expressed in Block 13 apply to this block as well.

Block 15: Identifies condition monitor and hard time replacement candidates. The comments expressed in Block 13 apply to this block as

Block 18: Identifies on condition candidates. The consideration of "When the on condition task does not maintain required reliability/safety levels, redesign should be considered.", should be eliminated from this block as on condition task has previously been established. This can be accomplished since the basis for the on condition candidate is an acceptable probability of detection of an impending failure.

Block 19: Identifies the alternative of hard time replacement prior to failure or condition monitor and replacement after failure. It is assumed that the replacement, if effective in averting failure, would be desirable over condition monitor after failure when considering a critical item. The condition monitor alternative should be eliminated from this block based on the hard time replacement task being effective and the alternative to hard time replacement being addressed earlier in the decision path (reference Block 4).

Block 20: Identifies candidates for hard time replacement prior to failure, redesign to permit on condition maintenance to detect impending failures, and on condition maintenance to detect failures. The redesign option should be eliminated from this block since it is addressed further into the decision process (reference Block 23). A hard time replacement should be recommended based on a yes answer from Block 10. What should be highlighted in this block is the acceptance criteria for on condition maintenance requirements to detect a hidden critical failure. If on condition maintenance for failure detection is not acceptable, redesign should be recommended.

Block 21: Identifies items for which there is no effective tasks for averting failure. The existing candidate is condition monitoring to detect failures. The alternative of redesign is properly indicated in this block.

Block 22: Identifies items for which there is no effective tasks for averting failure. The existing candidate is on conditon maintenance to detect failures. The alternative of redesign is properly indicated in this block.

Block 23: This block highlights hard time replacement tasks and recommends evaluation of redesign as an alternative. This logic is proper and should be retained in this block.

The changes recommended in the design logic are depicted in Figure XI-4.

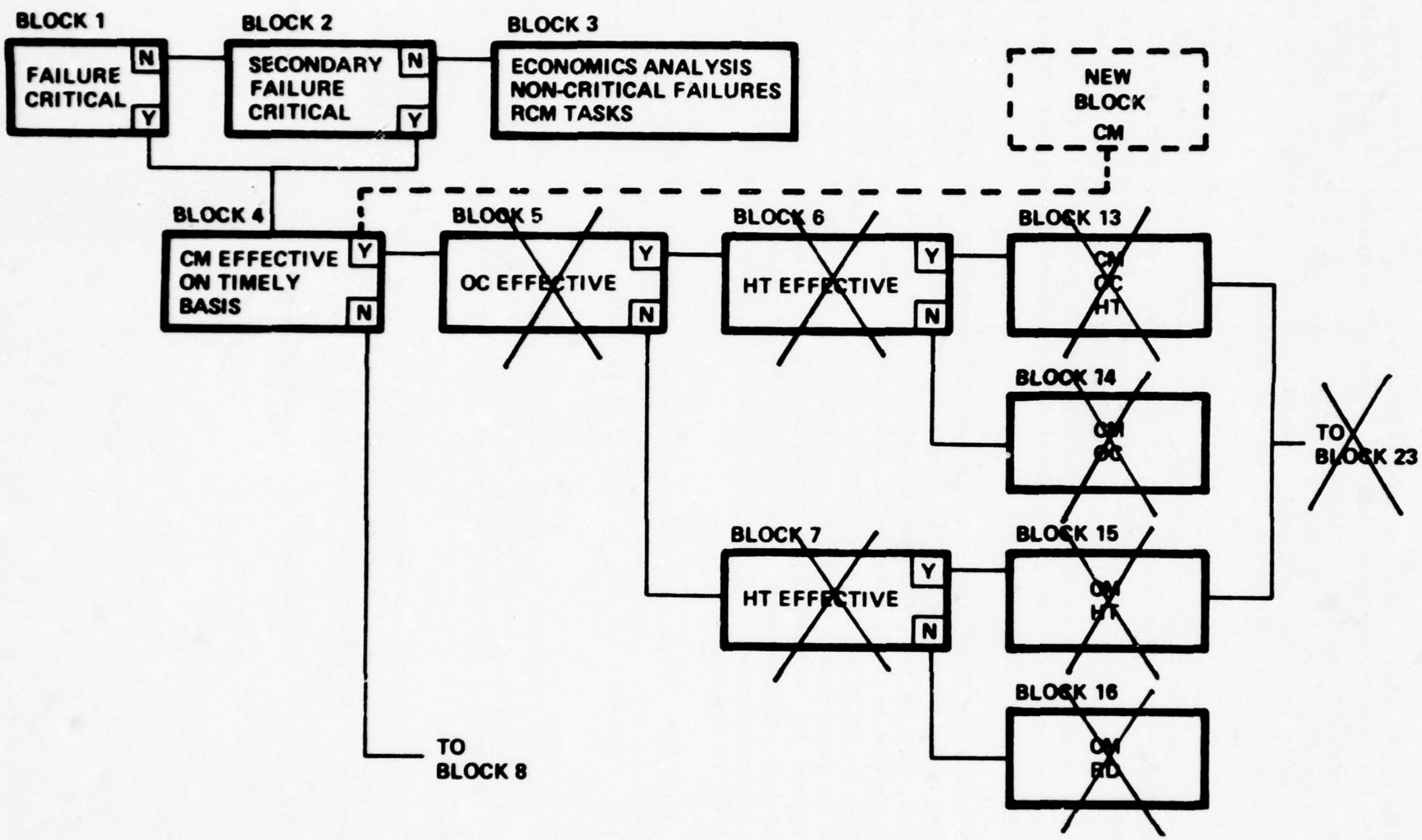

Figure XI-4. Impact of Evaluation Comments of RCM Logic (1 of 2)

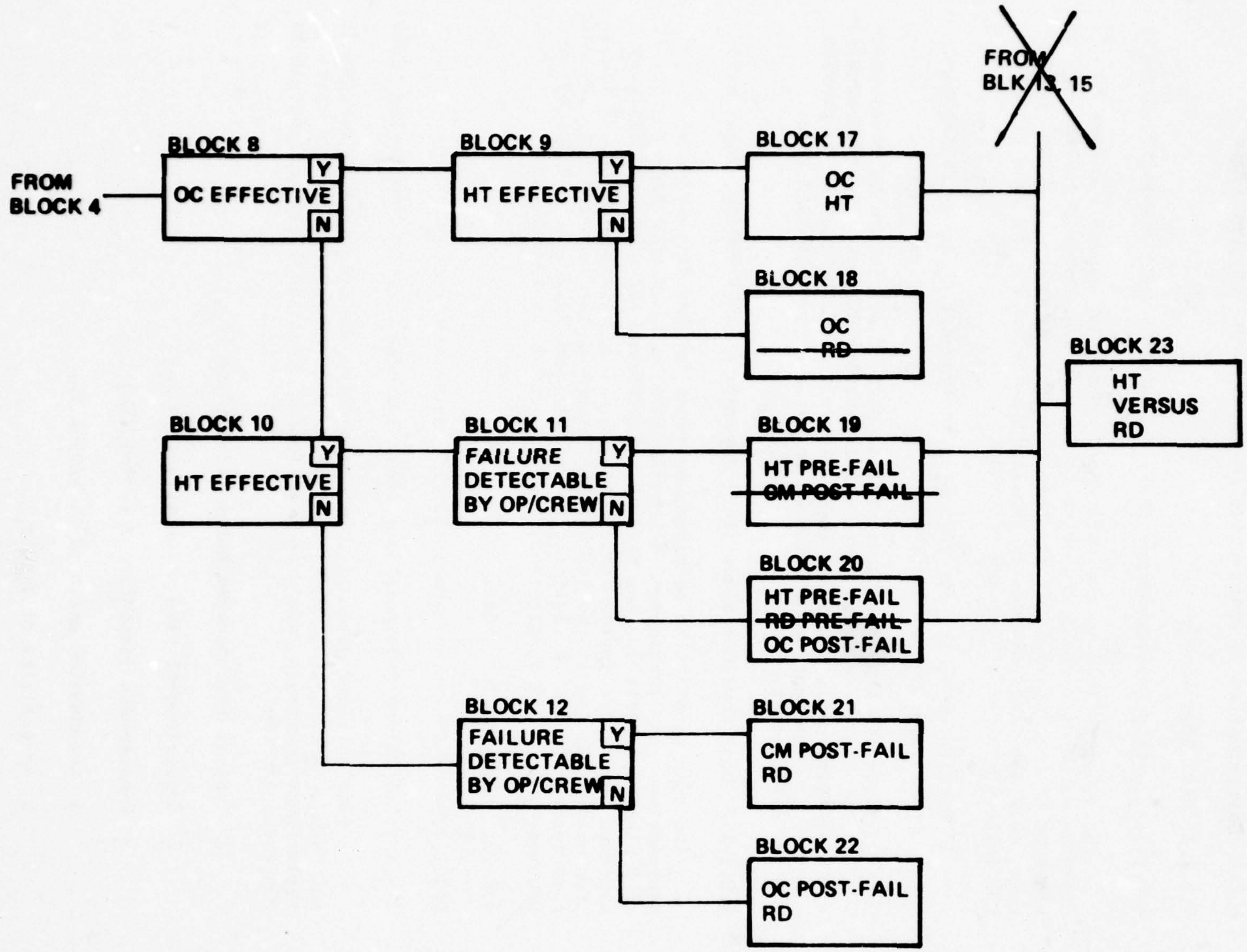

Figure XI-4. Impact of Evaluation Comments on RCM Logic (2 of 2)

4.2.1 Determination of Maintenance Intervals/Cost Considerations

4.2.1.1 Hard Time Limits

4.2.1.1.1 Safety Considerations (Ref: Appendix C, AMCP 750-16, Page C-17)

The example cited in the referenced section of Appendix C uses a discrete value of probability of no failure as the criteria for the determination of the interval for the hard time replacement. In actual practice, this detailed guidance is usually not available. In view of this, the following alternatives are offered:

1 Develop criteria, for inclusion in Appendix C, to establish hard time replacement intervals.

2 Since RCM considerations will be part of all future DA developmental system designs, develop quantitative RCM specification requirements, e.g., scheduled task intervals shall be such as to provide _____ percent probability of no failure prior to hard time replacement.

4.2.1.1.2 Cost Considerations (Ref: Appendix C, AMCP 750-16, Page C-18)

The cost equation to be minimized needs further discussion or explanation. Any replacement interval would be based on a high probability of replacement prior to item failure. Therefore, the number of failures expected during the replacement interval, $F(T_r)$, will be fractional (less than one). The longer the replacement interval, the less the cost per unit time appears to be. A clarification of the cost equation, perhaps by inclusion of a sample application, in this section is recommended.

4.2.1.2 On-Condition Limits

4.2.1.2.1 On-Condition - Detection of Imminent Failures

4.2.1.2.1.1 Safety Considerations (Ref: Appendix C, AMCP 750-16, Page C-20)

A more detailed discussion of the safety considerations is recommended. Use of a typical example, similar to that presented for hard time replacement intervals, would be beneficial. Specific items that should be addressed include:

1 Typical time between onset and failure (T_{os})

2 Comparison of time to onset versus T_{os}

3 Recommended inspection interval (T_i)

a Recommended ratio of T_i versus T_{os}

b Feasibility of $T_i < T_{os}$

4 Time accumulation on an item prior to start of an on condition maintenance program.

4.2.1.2.1.2 Mission Considerations (Ref: Appendix C, AMCP 750-16, Page C-22)

The cost equation to be minimized requires further discussion. The expected number of failures in the inspection interval (T_i) will be fractional. The longer T_i the less the cost per unit time appears to be. A clarification of the cost equation, perhaps by inclusion of a sample application, in this section is recommended.

4.2.1.2.2 On Condition - Detection of Failures

4.2.1.2.2.1 Mission Considerations (Ref: Appendix C, AMCP 750-16, Page C-23)

The cost equation comments for on condition maintenance to detect imminent failures in paragraph 4.2.1.2.1.2 are equally applicable to mission considerations for on condition maintenance to detect failures.

4.2.1.3 Condition Monitor Cost Considerations (Ref: Appendix C, AMCP 750-16, Page C-24)

The cost equation contains a questionable factor; namely, the additional total life cycle cost per end item by incorporating the warning device divided by the number of expected intervals during the life cycle (C_{WD}). For an end item to qualify for condition monitoring, the warning device must already be a part of the decision. C_{WD} should only be a cost factor when addition of a warning device is considered.

Normally there should be no cost associated with a condition monitor. The operator/crew is already assigned to a system and, through performance of normal duties, impending and actual failures can be detected. Therefore, impending or after failure detection costs do not appear to be legitimate cost factors. Whenever condition monitor is a cost alternative, it should be most effective.

4.2.2 Examples of Decision Logic Application

Example 1 (Ref: Appendix C, par C-11b): This sample case is well presented and is helpful in demonstrating the application of RCM logic. However, the results of the RCM analysis (disposition) are slightly misleading. The disposition indicated for all three failure modes reflects condition monitor and design review. Since condition monitor was previously deemed not to be feasible for the existing design, only design review should be reflected, as a result of the RCM analysis, in Figure C-5, page C-29 of Appendix C.

Example 2 (Ref: Appendix C, par. C-11C): This sample case is also well presented and is equally helpful in understanding the application of the RCM decison logic. However, it appears as though block 4 should have been answered "no" for failure modes 7 and 8. The discussion of these failure modes on page C-32 of the Appendix indicate condition monitor does not provide adequate levels of reliability and safety.

Example 3 (Ref: Appendix C, par. 11-d): This example is clearly presented and gives a good understanding of the logic application.

The three examples cover a variety of system/equipment situations and provides for a good practical working knowledge of the RCM decision logic application. Consideration should be given to integrating into one or more of the examples an application of the cost equations associated with on condition and hard time replacement tasks.

4.3 Recording of Logic Decisions

It is essential that the results of the RCM application to LSA be properly recorded. The modification of the LSA B sheet to include the results of the RCM analysis on the B06 card provides this capability. The portion of the B sheet applicable to RCM is shown in Figure XI-5. The modified B sheet facilitates the implementation of RCM into the LSA process by providing for:

1 The recording of answers to the applicable logic decision questions for each failure mode identified in the FMECA. Since LSA is an iterative process, this traceability is desirable.

2 The recording of the disposition of each failure mode. This provides the initial indication within LSA that an RCM maintenance task is required.

3 Documenting of the task code for each of the RCM maintenance tasks identified. The task code is a unique identifier for each maintenance or operator task associated with an item.

Changes in design of a developmental system or equipment may impact prior RCM decisions. Changes in the results of the RCM analysis are recorded on the B sheet identical to that of any other LSA data element change.

4.4 Implementation of RCM Decisions

Completion of the B sheet ensures implementation of the RCM analysis output into the makeup of the overall maintenance plan. Once an RCM task has been identified and its task code determined, it is treated within the LSA process as any other maintenance or operator task peculiar to the support/operation of a system or equipment.

RELIABILITY CENTERED MAINTENANCE ANALYSIS (APPENDIX C)

CARD NUMBER	a. LOGIC RESULTS — BLOCK NO. 1A	1B	2A	2B	3	4	5	6	7	8	9	10	11	12	b. DISPOS CM	OC	HT	DR	c. TASK ANALYSIS DOCUMENTATION — FGC/WBS/WUC	TASK CODE	SLN
B06A			Y	Y		Y	Y	Y							Y			N			
			Y	Y		Y	Y	Y							Y			N			
			Y	Y		Y	Y	Y							Y			N			
			Y	Y		N				Y	N					Y		N	1 0 4 0 3	B B O X X A A	
B06			Y	Y		Y	Y	Y							Y			N			

UPDATE CODE

Figure XI-5. LSA B Sheet - RCM Analysis Results

The task code is recorded on the C sheet (Task Analysis Summary) peculiar to an item indicating skill specialty codes, personnel requirements, task times, and support equipment requirements. A D sheet (Maintenance Task Analysis) is initiated for each RCM task to reflect sequential task steps, descriptive information for technical publications, information pertinent to personnel and training requirements, and identification of specific support equipment requirements.

The information provided on the C, D, and other LSA sheets will ensure inclusion of the support requirements peculiar to RCM into the maintenance plan. Changes in the RCM analysis, resulting from system/equipment design changes, will be reflected in updates of the C and D sheets and the maintenance support plan.

5.0 CONCLUSIONS

Analysis of Appendix C shows that the principles of RCM and the LSA process are highly compatible. The guidelines specified in the Appendix provide for the elements required for an effective RCM program.

The LSA provides the required input data, i.e., identification of maintenance significant items and FMECA data, for application to the decision logic. The decision logic, in general, reflects the fundamental principles of RCM. Modification of the B sheet is a logical step toward integration of RCM into the LSA process.

As an overall assessment, Appendix C, meets the requirement for providing the guidelines for incorporating RCM into maintenance plans in support of new systems/equipments. Incorporation of the recommendations set forth in section 6.0 should make Appendix C an even more effective tool for RCM implementation into the LSA process.

6.0 Recommendations

The following recommendations are offered as a result of evaluation of Appendix C to AMCP 750-16:

1 The instructions for application of each of the logic blocks should always identify the data source for determining the answers to decision questions.

2 Change the "yes" output of Block 4 of the decision logic to dead end into a condition monitor decision (Ref: par. 4.2, Block 4).

3 Modify the instructions for Block 18 to delete the redesign consideration as an alternative to on condition maintenance (Ref: par. 4.2, Block 18).

4 Modify the instructions for Block 19 to delete condition monitor after failure as an alternative (Ref: par. 4.2, Block 19).

5 Modify the instructions for Block 20 to delete the redesign to "provide on condition maintenance to detect impending failures" (Ref: par. 4.2, Block 20).

6 Include criteria in Appendix C for determining, if feasible, a discrete value of probability of no failure prior to hard time replacement; as a guide to establishing an effective replacement interval. In the absence of no discrete probability value being available, alternatives to establishing replacement intervals should be noted (Ref: par. 4.2.1.1.1).

7 Include a more detailed discussion and sample application of the safety considerations in determining on condition maitnenance intervals. Specific items that should be addressed include: time between on-set and failure (T_{OS}), typical ratio of maintenance interval (T_i) vs. T_{OS}, feasibility of $T_i < T_{OS}$, etc. (Ref: par. 4.2.1.2.1.1).

8 Incorporate sample applications of the cost equations when making cost considerations for on condition and hard time replacement intervals (Ref: par. 4.2.1.1.2, 4.2.1.2.2.1).

9 Clarify the cost considerations for condition monitor (Ref: par. 4.2.1.3).

10 Implement changes in the examples of the decision logic applications for examples 1 and 2 and include in the examples application of the cost equations associated with on condition and hard time replacement tasks (Ref: par. 4.2.2).

APPENDIX A

MARTIN MARIETTA PLAN FOR THE DEVELOPMENT OF A RELIABILITY CENTERED MAINTENANCE PROGRAM FOR EXISTING SYSTEMS/EQUIPMENT

OA 7815-3A

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CONTENTS

ILLUSTRATIONS

RELIABILITY CENTERED MAINTENANCE PROGRAM

1.0 INTRODUCTION

Maintenance planning has been one of the interrelated elements of logistic support for a number of years. As such, it is one of the support criteria that is normally integrated into the systems/equipment design at an early stage. As more efficient maintenance concepts are developed they are injected into newly developing systems/equipment. This leaves many systems/equipment in service with maintenance being performed in less efficient ways than have evolved through recent developments. In addition, as money for defense spending becomes tighter, these inefficient maintenance concepts consume a disproportionate share of dollars. Thus it appears that present maintenance concepts for currently fielded systems/equipment need modification to provide more efficient maintenance programs.

Martin Marietta, recognizing this need, has developed this plan for improving the maintenance concepts on existing systems/equipment. This plan is based upon the maintenance concept developed for civil aircraft by the Reliability and Maintainability Subcommittee of the Air Transportation Association. This concept is known as MSG-2.

2.0 PURPOSE

The purpose of this document is to provide a baseline of information for an objective evaluation of the Reliability Centered Maintenance (RCM) program as it is currently applied to existing Army maintenance programs. It uses the airline industry's MSG-2 concept as a foundation with additional flexibility incorporated to provide a broad application to a wide range of systems/equipment. It should be reasonably adaptable to accommodate specific requirements of individual or unique systems/equipment. It is not intended as an absolute, inviolate instrument for implementation but a general definition of Martin Marietta's approach to the RCM concept for maintenance program improvement.

3.0 BACKGROUND

The Reliability and Maintainability Subcommittee of the Air Transport Association has published a Maintenance Study Group document "Airline Manufacturer's Maintenance Program and Planning Document" (MSG-1), and later MSG-2, which describes a specific airline maintenance concept for new aircraft.

This concept was so successful in its initial application that the airlines applied it to maintenance programs of the older aircraft. The Navy has tailored the concept and successfully applied the concept to its P-3 aircraft under the name of Analytical Maintenance Program (AMP) and now is in the process of adapting the MSG-2 concept to other aircraft.

Through the issuance of POM 78-82, the Army established the requirement that the MSG-2 concept, under the title of Reliability Centered Maintenance (RCM), be incorporated on all Army weapon systems/equipment by the end of FY '79.

The RCM concept uses the application of decision logic to evaluate and logically construct maintenance tasks which are based on the systems/equipment functions and failure modes.

The RCM program consists of two groups of tasks:

1 A group of scheduled tasks (such as replacement, tests, inspections, etc.) to be accomplished at specific intervals. The objective of these tasks is to prevent deterioration of the inherent design levels of reliability.

2 A group of nonscheduled tasks which have been indicated as necessary by:

a The results of scheduled tasks accomplished at specific intervals

b Reports of malfunctions (usually originated by operator/crew)

c Condition monitoring (see below).

Tasks can be classified in terms of system wearout in three ways:

1 Hard Time Limit: A maximum interval for performing an overhaul or replacement maintenance task. Usually applies to items requiring periodic overhaul or items having a limited life expectancy which dictates scheduled removal/replacement.

2 On-Condition: Repetitive inspections or tests to determine the condition of units or systems, or portions thereof.

3 Condition Monitoring: For items that have neither hard time limits nor on-condition maintenance as their primary maintenance mode. Condition monitoring is accomplished on a nonscheduled basis by any appropriate means available for detecting conditions leading to failure or occurrence of a failure. This includes monitoring during periods of system/equipment operation on a non-interference basis, using means which range from notices of unusual conditions to specific analysis.

Application of RCM decision logic results in assigning maintenance work on a basis of scheduled tasks for items that fit the HARD TIME LIMIT or ON-CONDITION maintenance programs or, where no tasks are specified, the item is relegated to CONDITION MONITORING.

4.0 APPROACH

This program has been titled "Reliability Centered Maintenance (RCM)" because its basic exclusive purpose is to preserve or improve the inherent reliability of all systems and equipment through the determination and efficient performance of proper maintenance tasks.

Any maintenance program must have the capability for application to numerous systems/equipment, be specific in its contents, recognize a broad spectrum of conditions affecting maintenance performance, and prove to be cost-effective.

The development of an RCM program for existing military systems/equipment requires a large number of logic decisions pertaining to: 1) which individual requirements are necessary, 2) scope and frequency in which these requirements should be performed, and 3) impact on maintenance and support. Military application requires that the program be capable of application to a large variety of systems/equipment and at the same time be adaptable to the specific requirements of any individual system/equipment.

The maintenance program must cope with all systems/equipment whether of a simple or complex nature, which have a multiplicity of usage, which may be utilized in numerous environments, which may have a requirement to be maintained in constant condition of peak performance, and which must be capable of responding to emergencies with minimum or no maintenance actions. It is vital that the program result in maintenance being accomplished at a cost saving over the present maintenance programs.

The maintenance program must be so constructed to reduce and minimize the numerous outside influences which can affect the efficiency of any maintenance program.

With the above requirements in mind, the Martin Marietta Corporation has prepared this plan, for developing an RCM program for existing systems/equipment, which is displayed in block form in Figure 4-1. Each of four work packages comprising the plan is designed to accomplish a special group of related tasks which, when combined with the other three work packages, will produce a comprehensive maintenance program. The four work packages are:

1 Input data development
2 Application of decision logic
3 Comparative analysis
4 Preparation of documentation.

When the plan is applied to any system/equipment the result will be the creation of an RCM program, tailored specifically for that item of hardware, which will prevent deterioration of the inherent design levels of reliability and operating safety. Also, the plan provides a means of performing a comparative analysis between the former and new program wherein the scope and costs can readily be compared and evaluated. Documentation preparation should include recommendation and preparation of changes for the updating of technical publications and directives in order to eliminate any conflicting instructions.

4.1 Given below is a comprehensive listing of the various documents, records, drawings, charts, and forms that are necessary to provide the information used in implementing this program.

1 Technical publications
2 Technical bulletins
3 Maintenance directives
4 Army regulations and military specifications
5 Safety requirements and analyses
6 Development specifications

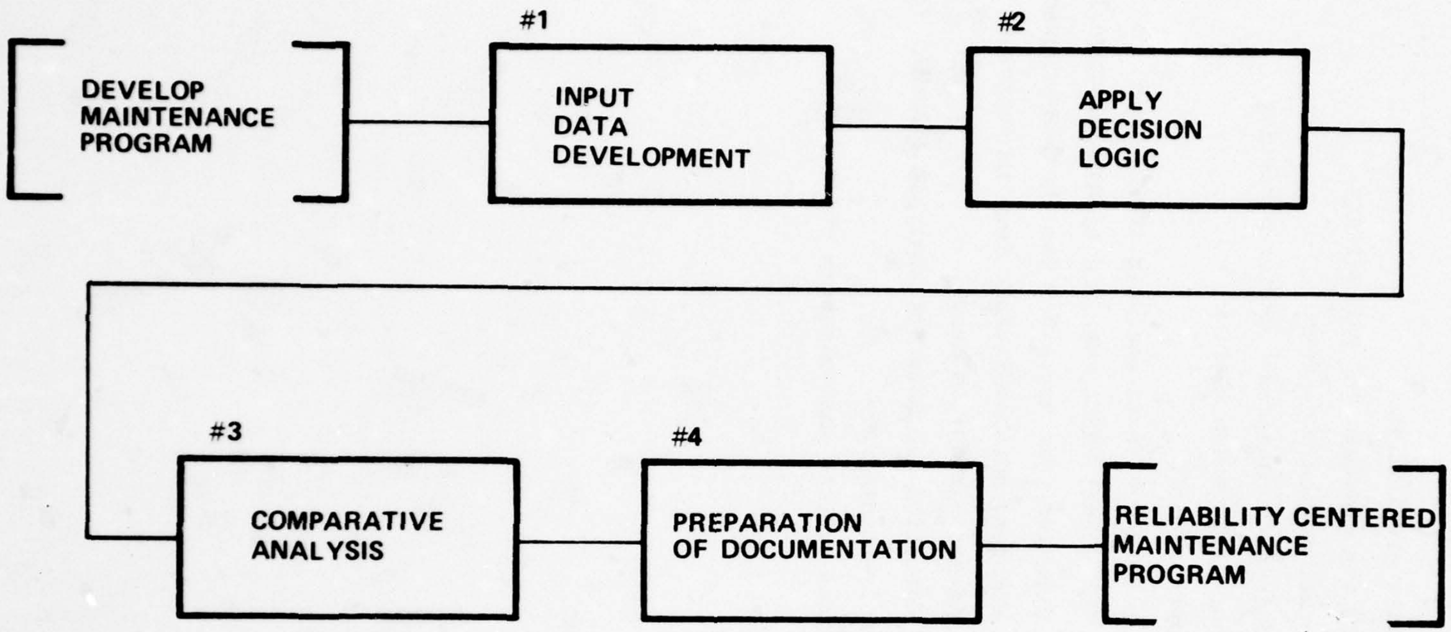

Figure 4-1. Four Work Package Approach

7 Reliability predictions

8 Manufacturing drawings and parts lists

9 Hardware generation breakdown

10 Army maintenance management center directives

11 Maintenance allocation charts

12 Maintenance records

13 Failure mode and effects analysis (FMEA) form

(NOTE: The formal FMECA required by MIL-STD-2070(AS) is more detailed than necessary for the RCM program, and a simpler, more applicable form is suggested when a FMECA is not already on hand.)

14 Failure detection and location analysis (FADALA) form

15 Decision logic diagrams

16 Maintenance process analysis work sheet forms

5.0 DEVELOPMENT OF THE RELIABILITY CENTERED MAINTENANCE PROGRAM (RCM)

The Martin Marietta plan for the development of an RCM program for existing military systems/equipments consists of four work packages, which when combined will provide the means for development of a comprehensive maintenance program. These work packages provide the essential steps for proceeding from the present maintenance program to a maintenance program based on decision logic applied to the possible equipment failure modes and their effects and consequences. The results of the application of this concept will be a maintenance program, the objectives of which are to utilize the latest and most cost-effective approaches, ensure the highest possible level of equipment performance, and retain equipment at a high percentage of mission readiness. The Martin Marietta Plan provides a logical technique for achieving an optimum balance among these three objectives so that a highly efficient overall program is formulated.

To obtain additional understanding of this Martin Marietta Plan, a thorough review of the Airline/Manufacture Maintenance Program Planning Document, MSG-2 is recommended. This document is the basis upon which the Martin Marietta approach to a decision tree logic maintenance program has been founded.

5.1 Work Package 1 - Input Data Development

The initial work package (Figure 5-1) includes a comprehensive analysis of the present maintenance program and the compilation of the input data necessary to the application of the Martin Marietta Plan in the development of an RCM program.

The most significant and driving force in developing the RCMS Maintenance Program is the technique of compiling, organizing, and analyzing the records and data required for application of the decision logic. Utmost care must be taken in the preparation of each of the work sheets

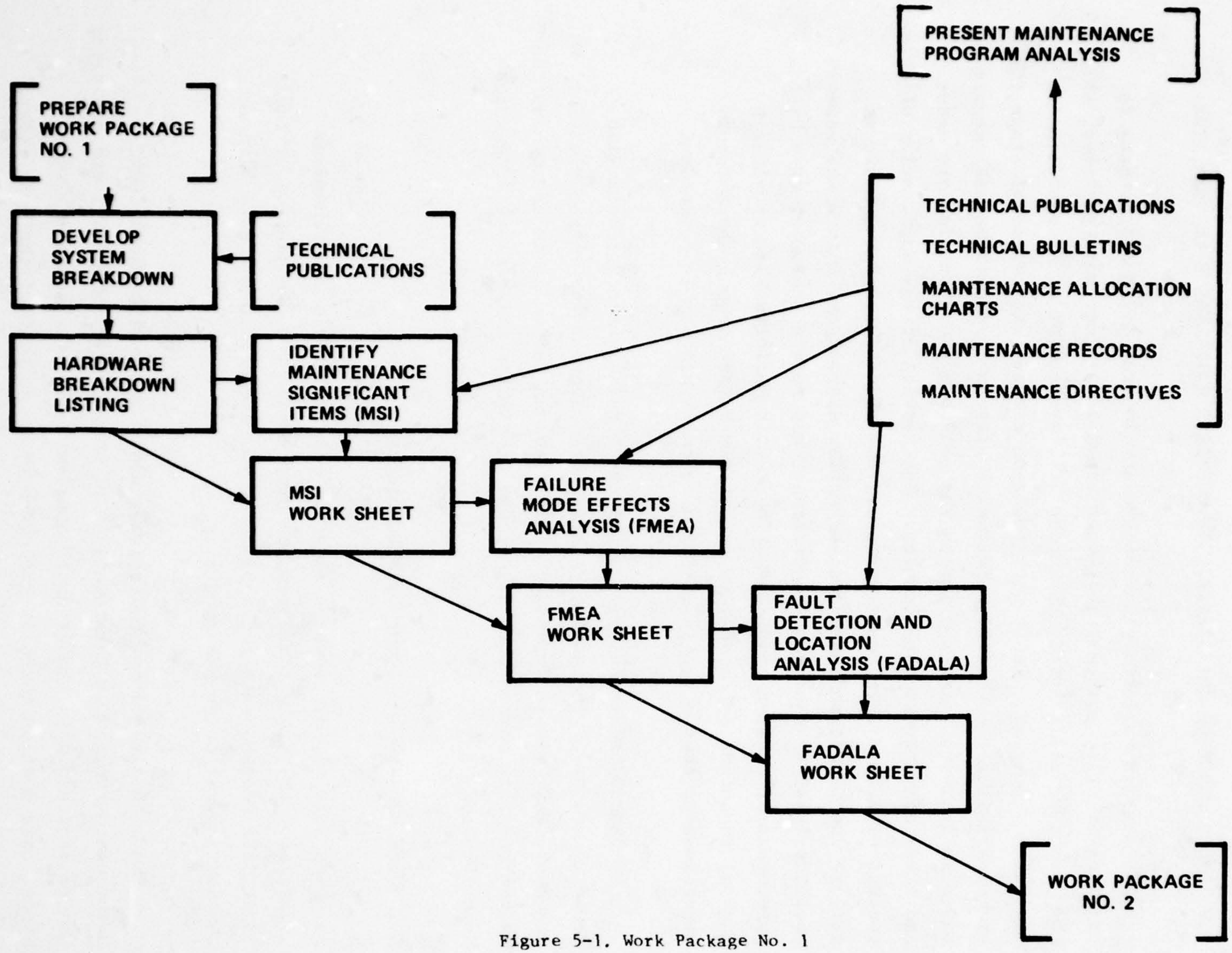

Figure 5-1. Work Package No. 1

for each Maintenance Significant Item (MSI). The data must be carefully screened applying only factual information since the inclusion of intuitive information where facts are needed could result in a false or misleading conclusion when the data is applied to the decision logic.

The group or individual(s) performing the analysis and collecting data on the present maintenance program must be thoroughly familiar with the maintenance and operation of the system/equipment. In addition, they must possess an understanding of the decision logic in order to screen from the available data those facts which are pertinent to the development of a comprehensive preventive maintenance program.

The analysis is performed through the preparation of a hardware breakdown listing and a series of three work sheets which contain the input data to be applied to the decision logic. Generation of a system/equipment hardware breakdown structure to the major item level is the initial step in the process. This generation breakdown is the input for identifying the maintenance significant items at which level the RCM program can be effectively applied. The Maintenance Significant Items (MSI) are compiled on an MSI work sheet that is used as the data source for conducting a Failure Mode and Effects Analysis (FMEA) for each of the maintenance significant items. The results of the analysis are entered on the FMEA sheet. With the FMEA work sheet serving as a source of input data, a Fault Detection and Location Analysis (FADALA) is accomplished for each failure mode identified, with the results documented on a third work sheet (FADALA).

(NOTE: The FMEA included in this program is a simpler and less intensive study than the FMECA (Failure Modes, Effects and Criticality Analysis) delineated in MIL-STD-2070(AS), and which is usually performed by a government contractor. If a FMECA is on hand, make use of it instead of preparing the described FMEA.)

By combining the data contained on the three work sheets, the maintenance requirements can be identified. These requirements can then be applied to the decision logic, work package No. 2, for development of the RCM Program.

When applied to a system/equipment that is comprised of a number of major components, each component in turn must be subjected to the analysis. As an example, if the PERSHING Pla System were the candidate for analysis, each of the PERSHING peculiar major components would be subjected to individual analysis; i.e., each of the four missile sections, erector launcher, programmer test station, power station, azimuth laying set, battery control center, radio terminal set system components test station. Also, the common components of equipment, i.e., trucks, communication sets, generators, etc., would require analysis. The analyses of the common components can be performed as part of the PERSHING System or may be considered as end items and subject to a separate maintenance program development under the auspices of the commodity command controlling the item. The breakdown level at which the analysis is to be accomplished will depend on the characteristic of the system/equipment.

As the initial task, the hardware items to be included in the analysis must be determined. To accomplish this, the system/equipment designated for maintenance analysis is structurally broken down into functional hardware levels: the system/equipment, group, and major item as a minimum, and further as required. A three-level system hierarchy is presented in Figure 5-2 followed by an example of the breakdown for the PERSHING Pla System, Figure 5-3. For some systems/equipment it may be necessary to structure the breakdown to additional levels in order to identify and obtain a workable level. The result of the effort is the selected hardware listing structured to each major end item level.

5.1.1 Maintenance Significant Item (MSI) Work Sheet

For each major item it will be necessary to perform an analysis to identify the maintenance significant items. Maintenance significant items

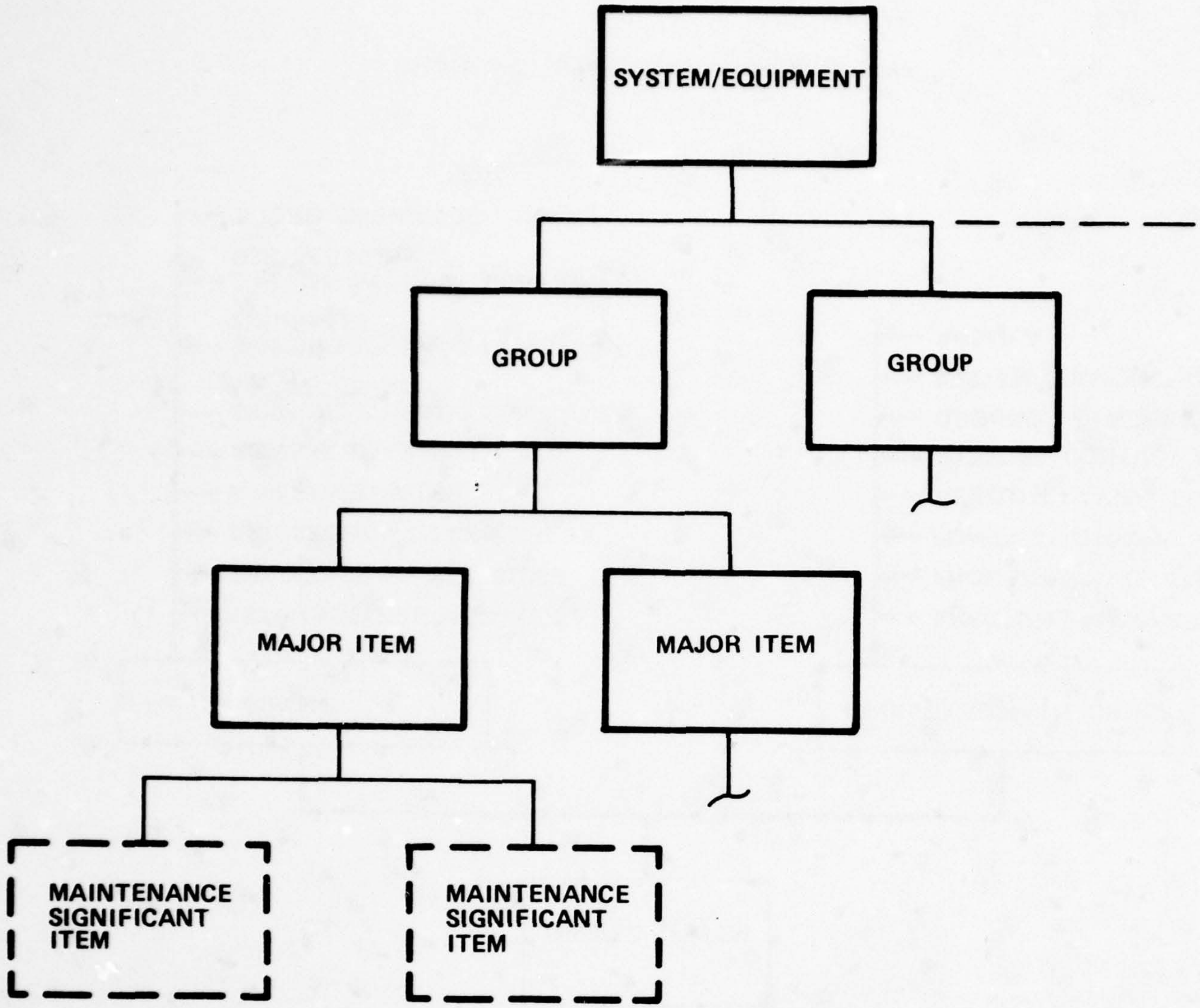

Figure 5-2. System Hardware Hierarchy

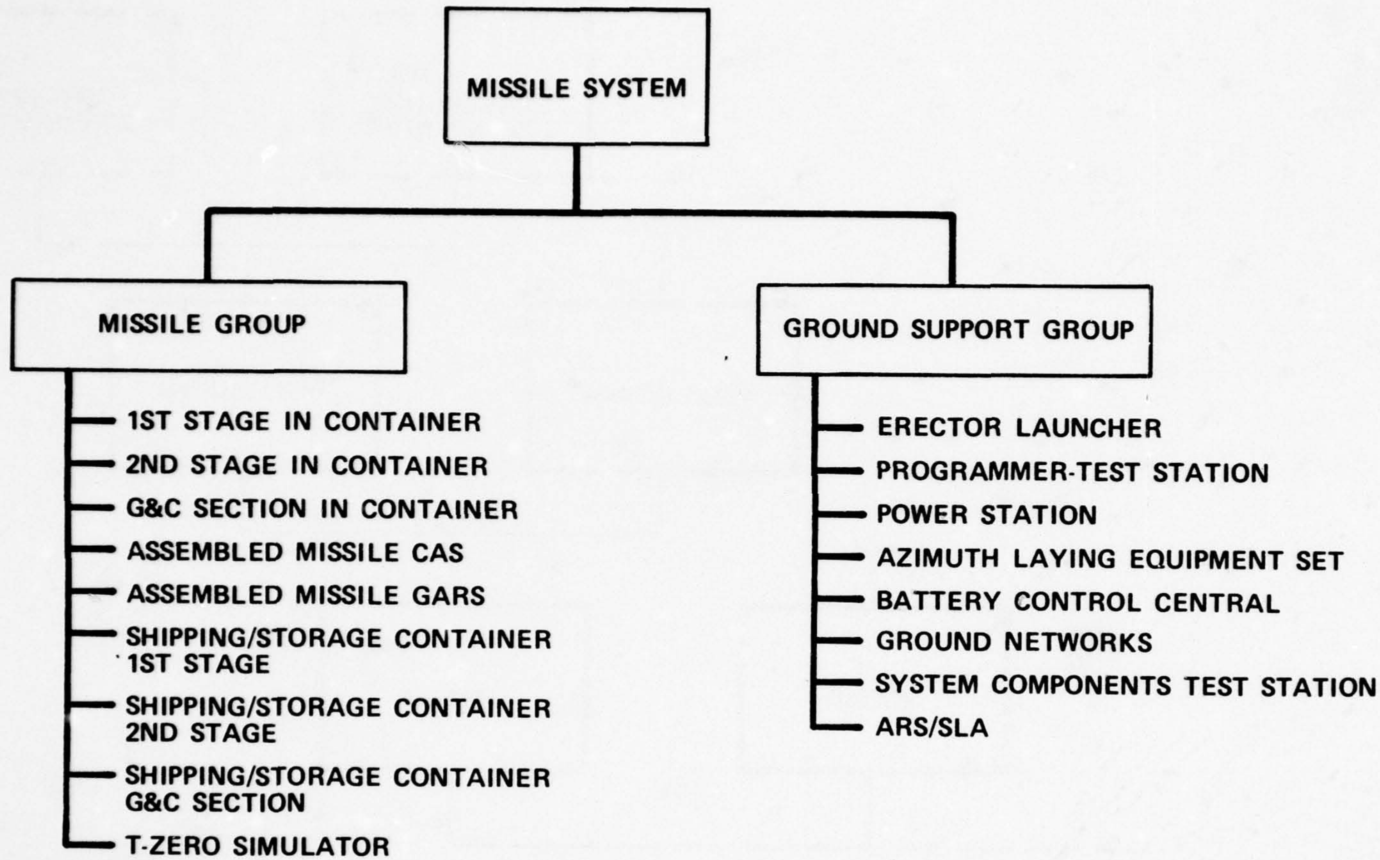

Figure 5-3. Typical Hardware Breakdown

(MSI) are those items which are necessary for completion of a mission without undue subjection of personnel and equipment to safety hazards plus any related items which might indirectly affect the primary item. MSI should include but not necessarily be limited to:

1 All items currently within the scope of the existing maintenance program
2 Items which are considered problem items (see below)
3 Items with inspections and/or tests required by applicable technical publications
4 Any other item judged to require analysis.

Problem items are defined as those items which contribute directly or indirectly to:

1 Mission failure (a malfunction which prevents the successful completion of a mission)
2 Aborts (termination of operations which result in mission cancellation prior to completion)
3 Mishaps (any occurrence which results in damage to equipment or injury to personnel)
4 Unsatisfactory conditions (an undesirable condition which is not severe enough to require an abort)
5 System/equipment degradation (a condition in which the equipment performance or potential capability is less than its designed, inherent capability).

The technical publications for each of the major end items are the most definitive source documents for performing the analysis that will result in the identification of all the maintenance significant items. Pertinent data concerning each MSI should be extracted and entered in the appropriate space on the MSI work sheet (Figure 5-4), which serves as the starting point for subsequent analysis.

AD-A063 559 MARTIN MARIETTA AEROSPACE ORLANDO FLA F/G 5/1
RELIABILITY CENTERED MAINTENANCE STUDY.(U)
SEP 78 R TIPTON, R BOEMLER, J ROBINSON DAAG39-77-C-0169
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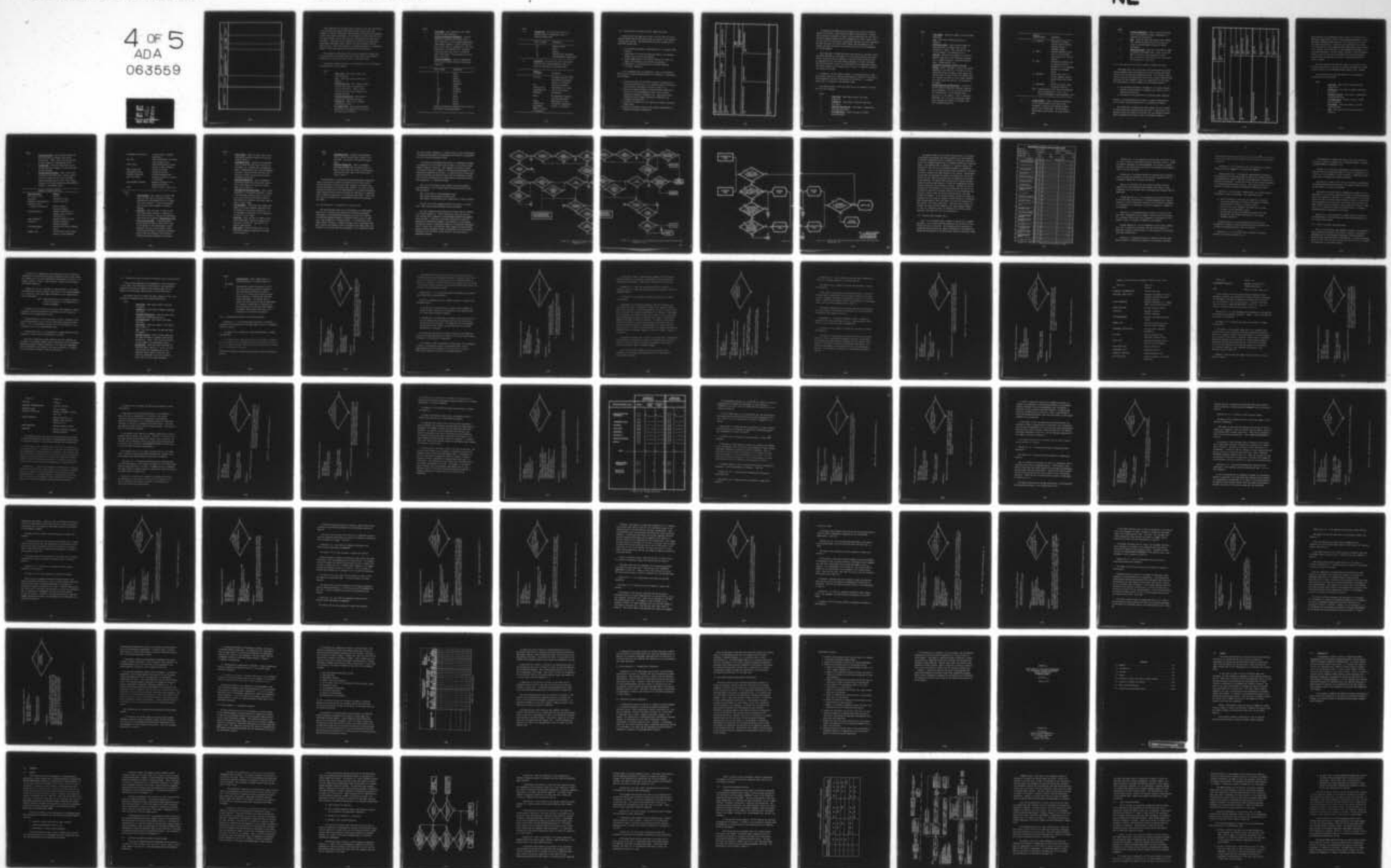

<table>
<tr><td colspan="2">MAJOR ITEM
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(2)</td><td>REVISION NO./DATE
(3)</td><td colspan="2">PREPARING ORGANIZATION
(4)</td><td colspan="2">PREPARED BY
(5)</td></tr>
<tr><td colspan="2">MSI NOMENCLATURE
(6)</td><td>PART NUMBER
(7)</td><td colspan="2">EXISTING MAINTENANCE REQUIREMENT
(BRIEF DESCRIPTION) (8)</td><td>INSP
FREQ (9)</td><td>PROBLEM
ITEM (10)</td><td>DISPOSITION
(11)</td></tr>
<tr><td colspan="2"></td><td></td><td colspan="2"></td><td></td><td></td><td></td></tr>
</table>

Figure 5-4. Work Sheet - Maintenance Significant Items (MSI)

When completed, the work sheet will provide for each MSI a description of the existing maintenance requirements, which include servicing, inspection, testing, calibrating, and replacement, along with the frequency at which each task is performed. If the failure of an MSI could result in a serious problem, the type of problem is identified and entered on the work sheet. Also shown is the disposition of each currently scheduled maintenance requirement, which results from the evaluation using the decision logic. This entry provides a convenient setting for a comparison between the existing maintenance program and the RCM program.

Any changes in maintenance tasks should be prominently marked with a vertical bar on the revised sheet next to the change to draw special attention to the deviation from current or previous actions.

The various columns and blocks of the work sheet are to be completed in accordance with the following:

Block	
1	MAJOR ITEM. Enter name of major item under evaluation
2	DATE. Enter date on which work sheet is prepared
3	REVISION NO./DATE. Enter revision number and date work sheet is changed after initial preparation. (Note: Place a vertical bar next to each change in its appropriate block)
4	PREPARING ORGANIZATION. Enter name of organization preparing work sheet.
5	PREPARED BY. Enter name of engineer preparing work sheet.
6	MSI NOMENCLATURE. Enter each Maintenance Significant Item identified for the major end item listed in Block 1.

Block

7 **PART NUMBER**. Enter appropriate part number beside each MSI identified.

8 **EXISTING MAINTENANCE REQUIREMENT**. From the appropriate technical publication, enter a brief description of all scheduled maintenance requirements currently in effect against the MSI or enter "None" if appropriate. List each requirement on a separate line. (Examples: "Remove and Clean Air Filter", "Change Oil Every 6,000 miles", "Check Pressure and Fluid Level in System".)

9 **INSPECTION FREQUENCY**. Enter the appropriate code for each beside maintenance requirement identified.

BLOCK 9 CODES	DEFINITION
D	Daily
W	Weekly
M	Monthly
Q	Quarterly
SA	Semiannual
A	Annual
A+1/2	18 Months
A+4	60 Months
50	50 Hr
100	100 Hr
300	300 Hr
500	500 Hr
S#	Special

It may be necessary to establish other codes for some specific systems/equipments.

Block

10 **PROBLEM ITEM.** If the MSI is known to be a problem, enter the appropriate code to identify problem area.

BLOCK 10 CODES	DEFINITION
MF	Mission Failure
A	Aborts
M	Mishaps
US	Unsatisfactory conditions
SD	System/equipment degeneration

11 **DISPOSITION.** For each item, enter final disposition of the current maintenance task as a result of application of decision logic.

BLOCK 11 STATEMENTS	DEFINITION
No Action	No change required in the maintenance requirement, process, or frequency.
Add (Identify new requirement and frequency)	Add new maintenance requirement, i.e., hard time or on-condition maintenance.
Delete	No maintenance required - condition monitoring.
Change (Identify new requirement, change to process or frequency)	Modification of the maintenance requirement, process, or frequency.

5.1.2 Failure Mode and Effects Analysis (FMEA) Work Sheet

Using the MSI work sheet as an input a Failure Mode and Effects Analysis (FMEA) will be performed, which will result in the predicted failure mode listings. The effectiveness by which an FMEA can be performed depends upon:

1 The performing engineer's understanding of the hardware being analyzed
2 Preciseness of the failure modes description, its immediate effects, and its final consequences
3 Proper summarization of the failure mode and its effect on higher level hardware, plus ultimate consequences
4 Consistency of the application of technique among RCM development engineers.

It is recommended that the engineer(s), prior to performing an FMEA, acquire a detailed understanding of the hardware by undertaking the following:

1 Collect and review all available technical documentation on the major hardware items, i.e., technical manuals, directives, specifications, maintenance allocation charts, etc.
2 Discuss the hardware design, at the maintenance significant item level, with knowledgeable persons, such as users, maintenance personnel, designers, etc., specifically questioning the failure modes, performance parameters, and consequence probabilities.
3 Formulate the approach to the analysis and identify potential difficulties.
4 Review the analytical results with persons knowledgeable in hardware maintenance requirements.

<table>
<tr><td colspan="2">MAJOR ITEM
(1)</td><td colspan="2">PREPARED BY
(2)</td><td colspan="3">PREPARING ORGANIZATION
(3)</td></tr>
<tr><td colspan="3">MSI NOMENCLATURE
(4)</td><td>PART NUMBER
(5)</td><td>DATE
(6)</td><td colspan="2">REVISION NO./DATE
(7)</td></tr>
<tr><td colspan="7">FUNCTION
(8)</td></tr>
<tr><td colspan="5" rowspan="2">REDUNDANCY SIGNALLING DEVICES, FAIL SAFE DEVICES, ETC.
(9)</td><td colspan="2">MTBF
(13)</td></tr>
<tr><td colspan="2">PREDICTION SOURCE
(14)</td></tr>
<tr><td colspan="2">FAILURE MODES & CLASSIFICATION
(10)</td><td colspan="3">FAILURE EFFECTS
(11)</td><td colspan="2">FAILURE CONSEQUENCES
(12)</td></tr>
<tr><td colspan="7">ARE THERE ANY SPECIAL CONSIDERATIONS NEEDED TO RETAIN SAFETY/RELIABILITY?
(15)</td></tr>
</table>

Figure 5-5. Failure Mode and Effects Analysis (FMEA)

In preparing the FMEA work sheet (Figure 5-5), relate the failure effects of each MSI to operational and safety considerations. Failures should always be expressed in terms of effects associated with the unit's output(s) whenever possible and the consequences of output change. When an item can fail in more than a single mode, identify each mode separately. The more precisely the failure mode, effects and consequences can be defined, the more worthwhile the analysis will prove in the development of the RCM program.

When completed, the FMEA work sheet will provide for each MSI a brief functional description, the identity of any system redundancy that would nullify the effects and consequences of the MSI failure during mission, an explanation of any fail-safe devices designed to protect the system from the MSI failure, as well as a description of any signalling devices that would indicate to the operator/crew a failure or imminent occurrence of a failure of the MSI.

In addition, the work sheet contains a concise description of each failure mode along with a narrative describing the effects of the failure, its consequences, and the classification of the failure. It provides source data to be applied to the decision logic.

The various blocks of this work sheet are to be completed in accordance with the following:

Block	
1	<u>MAJOR ITEM</u>. Enter name of major item under evaluation.
2	<u>PREPARED BY</u>. Enter name of engineer preparing work sheet.
3	<u>PREPARING ORGANIZATION</u>. Enter name of organization preparing work sheet.
4	<u>MSI NOMENCLATURE</u>. Enter the name of the MSI being evaluated.

Block	
5	PART NUMBER. Enter part number of the MSI being evaluated.
6	DATE. Enter date on which work sheet is prepared.
7	REVISION NO./DATE. Enter revision number and date work sheet is changed after initial preparation. (Note: Place vertical bar next to each change in its appropriate box.)
8	FUNCTION. Describe the functions of the MSI in generic terms such as the "Verb-Noun" approach (i.e., "signal-processor", "pressure-hydraulic pump", "support-shaft", etc.)
9	REDUNDANCY, SIGNALLING DEVICES, FAIL-SAFE DEVICES. Enter a listing of items in the system redundant to the function of the MSI; list such signalling devices as lights, flags, gages, and switches that are used to alert the operator/crew of a failure; and list any other design features that would cause the results of the failures to be benign.
10	FAILURE MODES AND CLASSIFICATION. List each of the MSI failure modes from a physical characteristic standpoint. The failure should describe the "failed-state" or the condition after failure (i.e., "no output", "loss of pressure", "binding", etc.) For each failure mode identified, classify the failure in accordance with the following definitions:

BLOCK 10 CLASSIFICATION	DEFINITION
1) Critical	May result in mission failure, aborted mission, personnel injury or equipment damage.
2) Major	Requires immediate attention; if not corrected could lead into a critical failure.
3) Minor	Undesirable condition; has no immediate effect on mission; will not jeopardize personnel or equipment safety.
4) Dependent	Failure must occur in another component before stated failure mode could occur.
5) Independent	Failure not direct result of outside influence.

NOTE: Classification 4 and 5 must be associated with classification 1, 2 and 3 (i.e., Critical-independent, Minor-dependent, etc.)

11 <u>FAILURE EFFECTS</u>. Enter a narrative description of all direct effects of the failure mode including a listing of the symptoms by which failure can be identified. The description should amplify and explain the stated failure mode.

Block	
12	<u>FAILURE CONSEQUENCES</u>. Enter a narrative description of the probable ultimate consequences to establish the criticality.
13	<u>MTBF</u>. Enter the mean time between failure (MTBF) from reliability predictions or from data contained in the maintenance records of actual performance.
14	<u>PREDICTION SOURCE</u>. Enter (P) if the MTBF is based on predicted reliability data. Enter (A) if the MTBF is based on actual maintenance records.
15	Enter any special considerations that would affect the maintenance of this item.

5.1.3 Fault Detection and Location Analysis (FADALA) Work Sheet

Using FMEA work sheet as the input, Fault Detection and Location Analysis (FADALA) will be performed for each failure mode associated with each of the maintenance significant items. The technical publications along with the maintenance records for the major hardware items will serve as the information source for completing this work sheet. The effectiveness at which a FADALA can be performed depends on:

1 The performing engineer(s) knowledge of the trouble shooting methods and their ability to interpret the contents of the technical publications

2 Consistency in the application of technique among engineers.

Therefore, all RCM engineers must acquire a complete understanding of the trouble shooting methods prior to performing the FADALA.

When completed, the FADALA work sheet (Figure 5-6) will provide, for each failure mode associated with each MSI, a description of the methods by which the failure is detected, the test equipment requirements, maintenance task time in terms of maintenance manhours,

<table>
<tr><td colspan="2">MAJOR ITEM
(1)</td><td colspan="2">PREPARED BY
(2)</td><td colspan="2">PREPARING ORGANIZATION
(3)</td></tr>
<tr><td colspan="2">MSI NOMENCLATURE
(4)</td><td colspan="2">PART NUMBER
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(6)</td><td>REVISION NO./DATE
(7)</td></tr>
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<tr><td colspan="5" rowspan="2">FAILURE DETECTION METHOD
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(11)</td></tr>
<tr><td>SKILL LEVEL
(12)</td></tr>
<tr><td colspan="5" rowspan="2">TEST EQUIPMENT
(10)</td><td>MAINTENANCE LEVEL
(13)</td></tr>
<tr><td>DETECTION PROBABILITY
(14)</td></tr>
<tr><td colspan="5" rowspan="2">DETERIORATION DETECTION METHOD
(15)</td><td>TASK TIME
(17)</td></tr>
<tr><td>SKILL LEVEL (S)
(18)</td></tr>
<tr><td colspan="5" rowspan="2">TEST EQUIPMENT
(16)</td><td>MAINTENANCE LEVEL
(19)</td></tr>
<tr><td>DETECTION PROBABILITY
(20)</td></tr>
</table>

Figure 5-6. Fault Detection and Location Analysis

identification of the maintenance level at which troubleshooting is performed, required skill level of the maintenance personnel, and the estimated probability prediction that the troubleshooting procedure will detect the failure. In addition, the work sheet will contain (1) a description of the methods by which deterioration that can lead to the failure can be detected, (2) test equipment requirement, (3) task time requirement, (4) skill levels required, (5) the maintenance level at which the task can be performed, and (6) the probability estimate that the procedure will detect a deteriorating condition prior to failure.

This work sheet provides the data source to be applied to the decision logic as well as the data to evaluate the impact of the RCM concept on some of the Integrated Logistic Support (ILS) elements.

The various blocks of the work sheet are to be completed in accordance with the following:

Block	
1	MAJOR ITEM. Enter name of major item under consideration.
2	PREPARED BY. Enter name of engineer preparing work sheet.
3	PREPARING ACTIVITY. Enter name of organization preparing work sheet.
4	MSI NOMENCLATURE. Enter the name of the MSI being evaluated.
5	PART NUMBER. Enter part number of the MSI being evaluated.
6	DATE. Enter date on which the work sheet is prepared.

Block

7 **REVISION NO./DATE.** Enter revision number and date work sheet is changed after initial preparation. (NOTE: Place vertical bar next to each change in its appropriate block.)

8 **FAILURE MODE.** Enter key words from block 10 of FMEA work sheet (Figure 5-5) which describe the failure mode.

9 **FAILURE DETECTION METHOD.** Enter a brief description of the method used to detect failure. This could range from the use of the human senses performing visual, aural, touch, smell inspections to highly complicated spectrographic analysis. See examples below.

METHOD OF FAILURE DETECTION

Detection Method	Results
Bit (built in test)	Go-no-go
Functional	Variance from norm
Diagnostic Instrumentation	Variance from norm
Functional check:	
Operators instruments	Process variable Improper responses
Visual Inspection	Abnormal conditions, i.e., damage, leaks, activity/inactivity, etc.
Sound Inspection	Abnormal sounds/no sounds
Touch/feel	Abnormal vibrations Improper responses
Test/measurements	Variance from normal numerical values
Dynamic test	Proof/recertification loads - failure to meet standards

Performance verification	At rated loads - degraded performance
Age check	Excess statistical life expectancy, fatigue factor
Static check	Proof/recertification loads - failure to meet standards
Power rating test	Variance from norm
Environmental check	Undesirable effects
Dismantle inspection	Excessive/abnormal wear
Duty cycle check	Extensive periods of activity or inactivity
Spectrographic analysis	Abnormal concentration of chemicals/materials
X-ray	Defects (cracks, flaws, etc.)

Block

10 TEST EQUIPMENT. Enter name, part number, NSN number for any test or inspection equipment associated with performing the test or inspection cited in Block 9. Identify maintenance level at which test equipment is presently assigned.

11 TASK TIME. Enter the time, in terms of maintenance man-hours, required to complete the task cited in Block 9. Only active maintenance times should be considered; administrative time is not to be included. Actual maintenance records should be used to obtain these times. In the absence of valid maintenance records, predicted time may be used; however, these times should be based on established standards such as Time Line Analysis, which should be identified and used throughout the analysis.

Block

12	SKILL LEVELS. Enter the skill level of the maintenance personnel required for the task cited in Block 9.
13	MAINTENANCE LEVEL. Identify the maintenance level at which the task cited in Block 9 is performed, i.e., organization, intermediate, depot, considering the three level maintenance structure. When other than the three level structure is used, identify level and note organization structure.
14	DETECTION PROBABILITY. Enter a reasonable percentage estimate that the method cited in Block 9 will detect and locate the failure mode cited in Block 8.
15	DETERIORATION DETECTION METHOD. Enter a brief description of any methods available to detect a deteriorating condition prior to an occurrence of the failure identified in Block 8. When methods are identical with those shown in Block 9, write "same".
16	TEST EQUIPMENT. Enter name, part number, NSN number of any test equipment associated with performing the tests cited in Block 15. If all equipment is identical to that identified in Block 10, write "same".
17	TASK TIME. Enter the time, in terms of maintenance man-hours, required to complete the task cited in Block 15. See Block 11 for detailed instructions.
18	SKILL LEVEL. Enter the skill level of the maintenance personnel required for the task cited in Block 15.

Block

19 MAINTENANCE LEVEL. Identify the maintenance level at which the task cited in Block 15 is performed. See Block 13 for detailed instructions.

20 DETECTION PROBABILITY. Enter a reasonable percentage estimate that the method cited in Block 15 will detect and locate a deteriorating condition that will lead to the failure mode cited in Block 8.

The completion of the three work sheets (Maintenance Significant Items, Failure Mode and Effects Analysis and Fault Detection and Location Analysis) provides source data necessary to evaluate each failure mode against the decision logic diagram. The result of this evaluation process will be the identification of potential maintenance tasks classifications which will satisfy the requirement for maintaining the inherent design levels of reliability and safety. These tasks will then be developed into a comprehensive Preventive Maintenance Plan (PMP).

5.2 Work Package No. 2, Application of Decision Logic

The Martin Marietta plan for the development of an RCM program makes use of a decision logic diagram for evaluating maintenance requirements in determining what maintenance actions are effective in detecting impending failures of essential items as well as ensuring a high probability of mission success. If a malfunction could affect safety, readiness, or mission success, then a maintenance task which restores the inherent level of reliability and helps ensure the integrity of the system must be accomplished. If a malfunction could

not affect safety, readiness, or mission success, then the performing of preventive maintenance is questionable and should be accomplished only if it proves economically sound.

The method for determining the content of a maintenance program is through the use of decision logic as shown in the two-part logic diagram (Figure 5-7 and 5-8). This diagram is the basis by which the evaluation process is applied to existing system/equipment at the maintenance significant item level. It uses data from existing technical publications and historical data from the maintenance records that have been evaluated and, in some instances, restructured under work package No. 1 to facilitate usage.

Part one of the decision logic diagram has been developed to provide answers to the following questions concerning each failure mode evaluation:

What is the value of each maintenance task?

When should each maintenance task be done?

What method of maintenance task classification is most suitable?

Part two of the logic diagram provides the answer to the question: Where should each maintenance task be performed?

The logic diagram has been developed with what might be referred to as "Robot Dimensions". Strict factual data should be used for each decision point, supported by knowledgeable engineering judgment where necessary. Injection of intuitive information or personal experience on dissimilar equipment could misdirect the maintenance planning and result in unnecessary expense or insufficient maintenance action. Proper use of the decision logic diagram will provide maintenance planning information based on established, factually-related information and, therefore, should result in the most effective maintenance program.

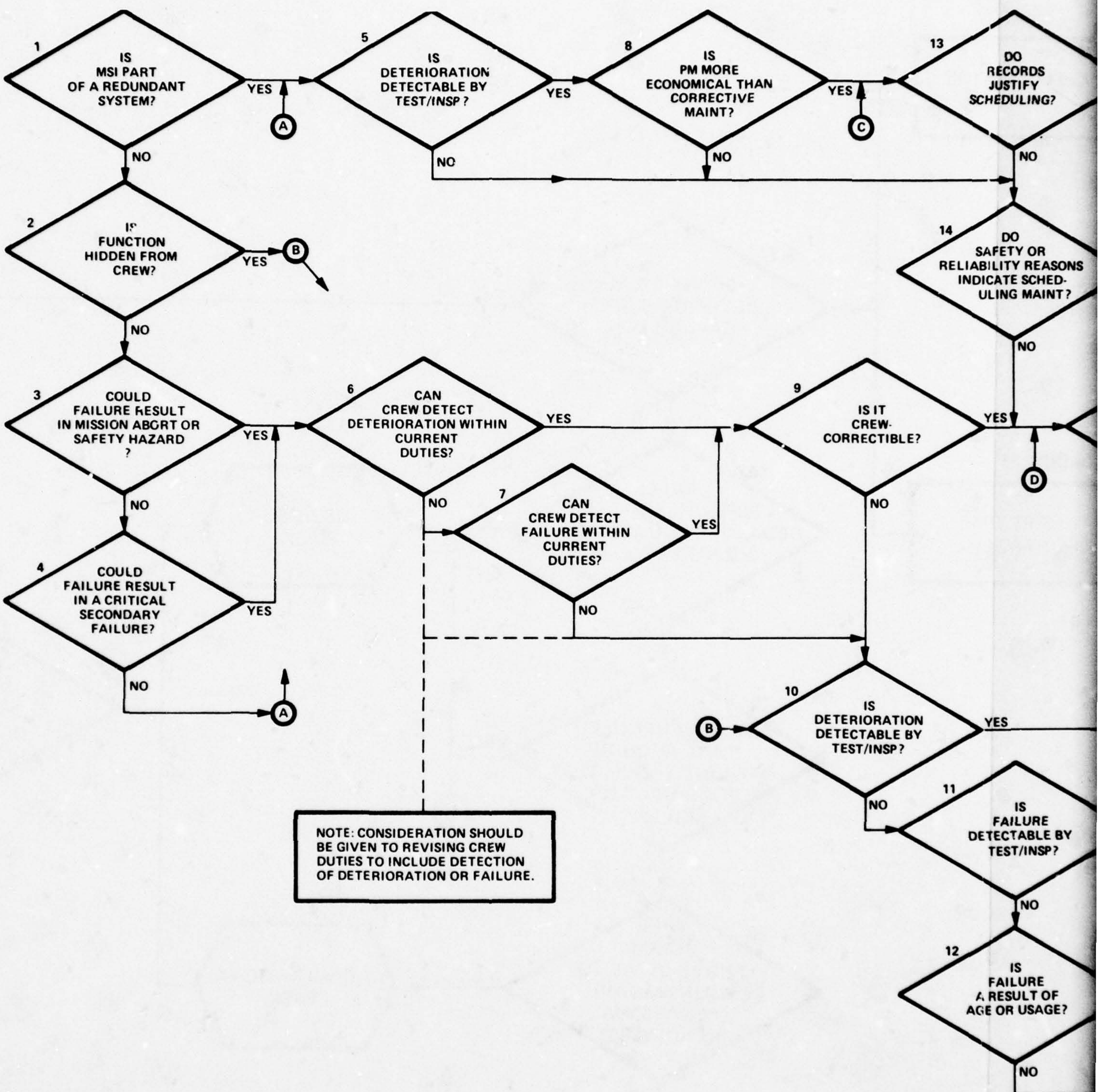


Figure 5-7. Reliability Centered Main
Diagram Part #1

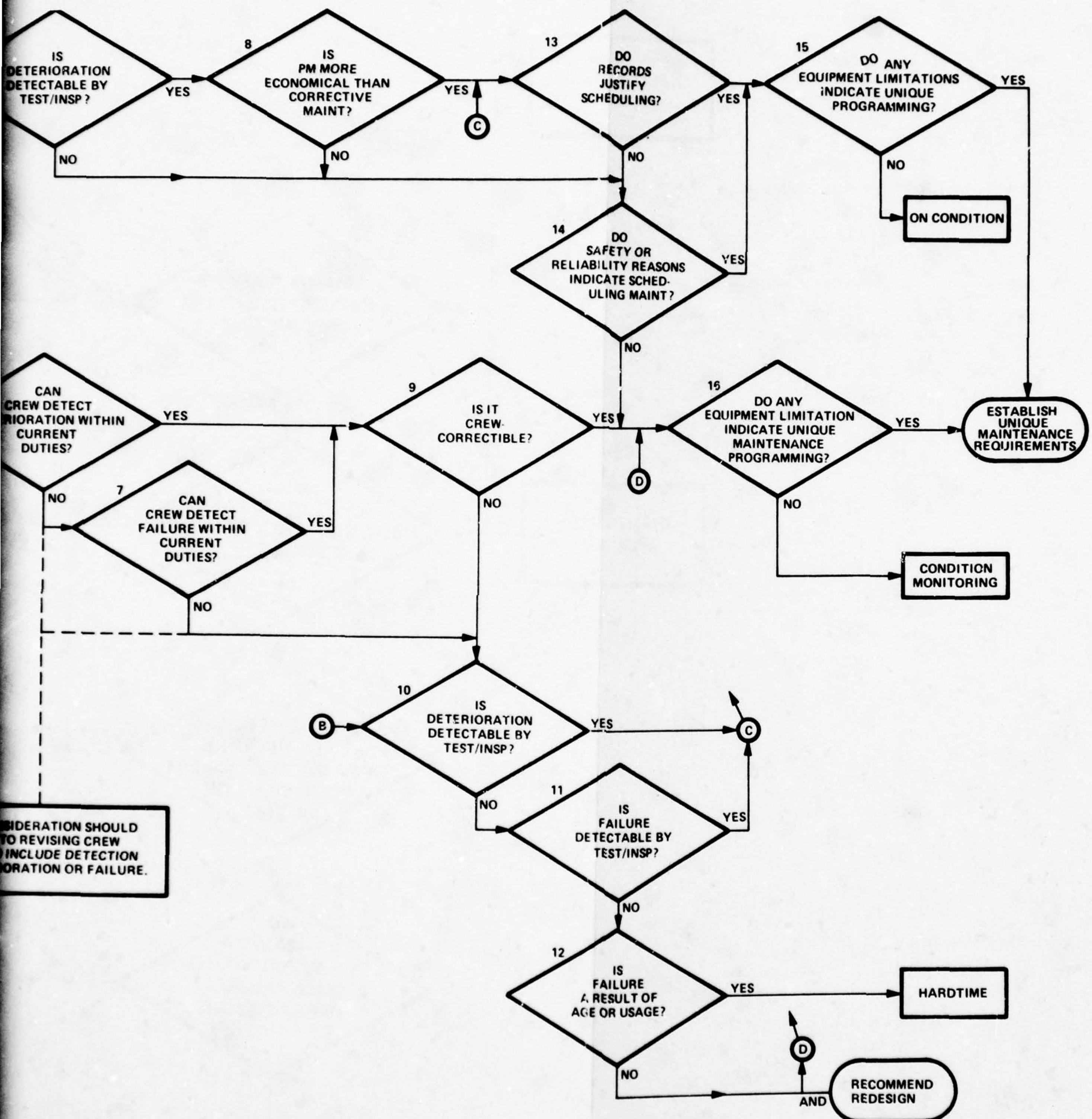


Figure 5-7. Reliability Centered Maintenance (RCM) Concept Decision Logic Diagram Part #1

2

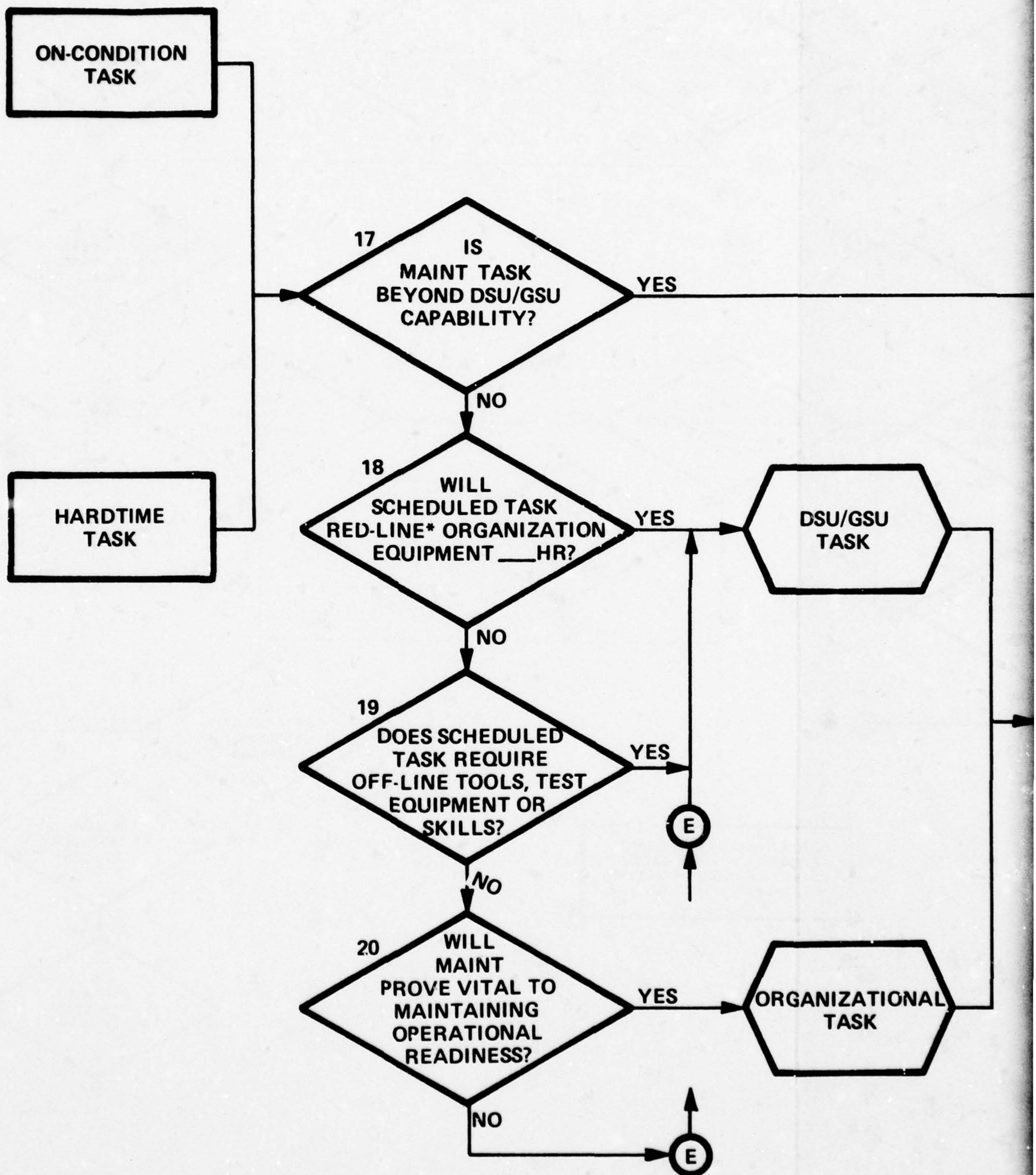
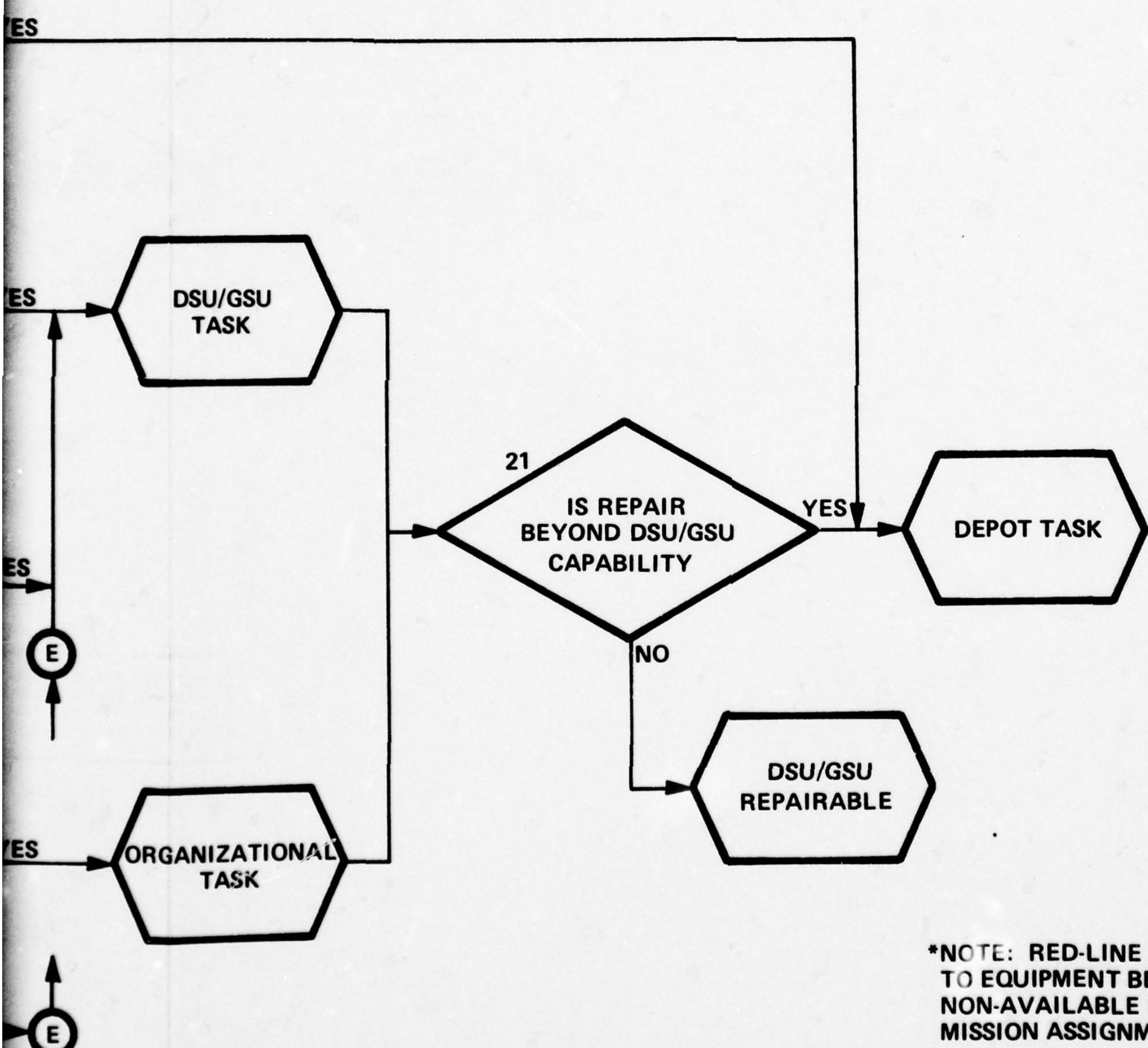

ON-CONDITION TASK
HARDTIME TASK
17
IS MAINT TASK BEYOND DSU/GSU CAPABILITY?
YES
NO
18
WILL SCHEDULED TASK RED-LINE* ORGANIZATION EQUIPMENT ___HR?
YES
NO
DSU/GSU TASK
19
DOES SCHEDULED TASK REQUIRE OFF-LINE TOOLS, TEST EQUIPMENT OR SKILLS?
YES
NO
E
20
WILL MAINT PROVE VITAL TO MAINTAINING OPERATIONAL READINESS?
YES
NO
ORGANIZATIONAL TASK
E

Figure 5-8.



*NOTE: RED-LINE REFERS TO EQUIPMENT BEING NON-AVAILABLE FOR MISSION ASSIGNMENT

Figure 5-8. Reliability Centered Maintenance (RCM) Concept Decision Logic Diagram Part #2

2

The approach taken in the decision logic process is to develop a maintenance plan whereby the final decision is the determination of whether a maintenance task is effective in detecting a deterioration of the inherent design levels of hardware reliability, operating safety, and readiness and, if effective, to ascertain whether the inclusion of the task in the maintenance program is economically worthwhile. Each of the logic questions must be answered in isolation in order to preserve the effectiveness of the process. Having asked the question and developed the answer, the analyst will follow the flow to the next question along the path as indicated by the answer to the question. He repeats this process until he passes through a series of questions and arrives at a point for designating the maintenance process and the maintenance location. Although the entire structure may seem complex, it is quite simple and very easy to use in practice; each YES or NO answer leads to but one succeeding question and, usually, there is only one task outcome for each path through the diagram. As the analyst proceeds through the series of questions, he will enter the results of each decision on the Maintenance Process Analysis (MPA) work sheet to aid in the evaluation of the results of the logic application. This work sheet, Figure 5-9, contains the questions which appear in the logic diagram, Figures 5-7 and 5-8. Additional space is available for inserting certain pertinent facts which will aid in the evaluation.

5.2.1 Decision Logic Diagram, Part I

Part I of the decision logic consists of sixteen (16) "trigger" questions. Four of these questions establish the criticality of the failure mode under evaluation. The remaining twelve questions are qualifying questions which are asked to determine the worthiness and scheduling requirements of the potentially effective maintenance tasks.

MAINTENANCE PROCESS ANALYSIS WORK SHEET

MAJOR ITEM: (1)	PREPARED BY: (2)	PREPARING ORGANIZATION: (3)	
NOMENCLATURE: (4)	PART NUMBER: (5)	DATE: (6)	REVISION NO. (7)

FAILURE MODE (S):	(8) A	(8) B	(8) C	(8) D
CLASSIFICATION:	(9) A	(9) B	(9) C	(9) D

LOGIC QUESTION		YES	NO	INFORMATION SUMMARY	
1. IS THE MAINTENANCE SIGNIFICANT ITEM PART OF A REDUNDANT SYSTEM?	A B C D			(10)	(11)
2. IS FUNCTION HIDDEN FROM CREW?	A B C D			(12)	(13)
3. COULD FAILURE RESULT IN MISSION ABORT OR SAFETY HAZARD?	A B C D			(14)	(15)
4. COULD FAILURE RESULT IN CRITICAL SECONDARY FAILURE?	A B C D			(16)	(17)
5. IS DETERIORATION DETECTABLE BY MAINTENANCE, TEST, OR INSPECTION?	A B C D			(18)	(19)
6. CAN CREW DETECT DETERIORATION WITHIN THEIR CURRENT DUTIES?	A B C D			(20)	(21)
7. CAN CREW DETECT FAILURE WITHIN THEIR CURRENT DUTIES?	A B C D			(22)	(23)
8. IS PREVENTIVE MAINTENANCE MORE ECONOMICAL THAN CORRECTIVE MAINTENANCE?	A B C D			(24)	(25)
9. IS IT CREW-CORRECTIBLE?	A B C D			(26)	(27)
10. IS DETERIORATION DETECTABLE BY MAINTENANCE, TEST, OR INSPECTION?	A B C D			(28)	(29)
11. IS FAILURE DETECTABLE BY MAINTENANCE, TEST, OR INSPECTION?	A B C D			(30)	(31)
12. IS FAILURE A RESULT OF AGE OR USAGE?	A B C D			(32)	(33)
13. DO MAINTENANCE RECORDS JUSTIFY MAINTENANCE SCHEDULING?	A B C D			(34)	(35)
14. DO SAFETY OR RELIABILITY REASONS INDICATE SCHEDULING MAINTENANCE?	A B C D			(36)	(37)
15. DO ANY EQUIPMENT LIMITATIONS INDICATE UNIQUE MAINTENANCE PROGRAMMING?	A B C D			(38)	(39)
16. DO ANY EQUIPMENT LIMITATIONS INDICATE UNIQUE MAINTENANCE PROGRAMMING?	A B C D			(40)	(41)
17. IS THE MAINTENANCE TASK BEYOND DSU/GSU CAPABILITY?	A B C D			(42)	(43)
18. WILL SCHEDULED TASK RED-LINE ORGANIZATIONAL EQUIPMENT > ______ HOURS?	A B C D			(44)	(45)
19. DOES SCHEDULED TASK REQUIRE OFF-LINE TOOLS, TEST EQUIPMENT, OR SKILLS?	A B C D			(46)	(47)
20. WILL MAINTENANCE PROVE VITAL TO MAINTAINING OPERATIONAL READINESS?	A B C D			(48)	(49)
21. IS THE REMOVED ITEM REPAIRABLE?	A B C D			(50)	(51)

Figure 5-9. Work Sheet - Maintenance Process Analysis (MPA)

Question No. 1 is to determine if the MSI under evaluation is one of a pair or more of parts which perform an identical function. Should the item be redundant, the system/equipment can continue to operate normally to the satisfactory conclusion of the mission even though one item of the pair has failed.

Question No. 2 determines whether the operator/crew can detect a failure through the observation of the function associated with the maintenance significant item under evaluation.

When it is determined that the function is hidden from the operator/crew, the maintenance/test methods, which ensure a high probability that the function will be available when required, must be identified.

Through Question No. 3 it is determined that should the MSI fail in the mode under consideration, the system/equipment could cease to function or function improperly resulting in the possible curtailment of the mission or it may result in injury to personnel or damage to the equipment.

Question No. 4 determines whether a failure of the MSI in the mode under consideration could trigger a reaction which could result in a secondary failure which could terminate in the abortion of the mission, injury to personnel or damage to the equipment.

Through Question No. 5 it is determined if there exists maintenance, test or inspection procedures that have the potential for detecting incipient conditions prior to the occurrence of the failure mode under consideration.

Question No. 6 determines whether the operator/crew have available the means to recognize the presence of an incipient condition

during normal equipment operation that could result in a system failure. All available means should be identified and documented for additional evaluation.

Question No. 7 is a follow-on to No. 6 but refers to a failure having occurred as opposed to a deteriorating condition.

Through Question No. 8 the engineer must determine the effects and consequences of the deterioration or failure and consider the cost in maintenance and support resources for performing both corrective or preventive maintenance. He must then choose the most desirable approach for developing the maintenance concept. This question results in a listing of potential, economically-beneficial maintenance tasks.

Question No. 9 has multiple considerations, all of which must be affirmative to yield a YES answer. The considerations are:

1 Does the operator or crew have the capability to perform on the spot maintenance to correct an incipient or failed condition prior to onset of a serious effect?

2 Can the tools, test equipment, and repair parts be made available at the operational level?

3 Can the repair action be accomplished without major dis-assembly and with minimal interruption of the system/equipment operation?

Through Question No. 10 a determination is made as to the availability of methods by which a deterioration in reliability can be detected through maintenance, test or inspection.

Question No. 11 is a follow-on which considers an occurred failure in the same context as No. 10.

A determination of whether the failure mode under evaluation occurs as a result of calendar time or operational usage of the MSI is accomplished with Question No. 12.

Question No. 13 provides a measurement for identifying the frequency in which the tasks identified as a result of Questions No. 8 and 10 are to be scheduled in order to provide a comprehensive maintenance plan in keeping with the RCM objectives.

Question No. 14 asks if there are any overriding considerations (including administrative directives) that preempt condition monitoring and demand on condition maintenance.

Limitations in certain types of equipment may require hard time replacement of an item even though more frequent on-condition maintenance is also required or desirable. An example would be an IFF transmitter tube which is usually replaced before failure at a fairly consistent usage-hour point but due to its combat criticality more frequent inspections are necessary to detect unexpected failures. Question No. 15 is inserted to ensure the identification of a unique, double-maintenance requirement in such cases.

Question No. 16 is included for a similar reason in case hard time replacement is indicated along with condition monitoring for a few, unique failure modes.

5.2.2 Part II, Decision Logic Description

Part II of the decision logic diagram consists of five questions which establish the validity of selection of specific locations for performing each of the preventive maintenance tasks with mission readiness and reliability/safety considerations. It helps the analyst select the most effective and efficient task location and also considers the disposition of the removed item(s).

Question No. 17 determines if the maintenance task is beyond the capabilities of the DSU/GSU maintenance organization and, hence, beyond the capability of the using organization's maintenance facilities. For example, overhaul, X-ray, or spectrographic analysis would be beyond the DSU/GSU capability.

Question No. 18 is to determine if the performance of the scheduled maintenance task will require "red-lining" of the system/equipment for a duration of time which makes maintenance at the organizational level unreasonable.

> NOTE: Red-lining refers to an equipment status in which the equipment is not available for a mission assignment.

Question No. 19 determines if the tools, test equipment or skills required to perform the preventive maintenance task are beyond the capability of the organizational level.

Through Question No. 20 an evaluation is made to determine if the potential maintenance task is vital to maintaining operational readiness. If not, a determination is made as to the advisability of performing the task at the organizational level.

Through Question No. 21 a determination is made whether the item removed at a lower echelon is repairable at the depot

When all the applicable logic questions have been answered, an analysis of the combined answers must be undertaken and the recommended maintenance program change(s) identified. The identical requirement may be identified as the answer to more than one question. Occasionally, this will be a natural result of the process.

5.2.3 Transferring Logic Decisions to Maintenance Process Analysis Form

Using the data generated in the preparation of Work Package No. 1 as an input, each identifiable failure mode for each maintenance significant item will be applied to the decision logic and the answer to each pertinent logic question on the MPA work sheet.

The various blocks of the MPA work sheet (Figure 5-9) are to be completed in accordance with the following instructions:

Block	
1	<u>MAJOR ITEM</u>. Enter name of major item under evaluation.
2	<u>PREPARED BY</u>. Enter name of engineer preparing work sheet.
3	<u>PREPARING ORGANIZATION</u>. Enter the name of the organization preparing work sheet.
4	<u>MSI NOMENCLATURE</u>. Enter name of MSI being evaluated.
5	<u>PART NUMBER</u>. Enter part number of MSI identified in Block 4.
6	<u>DATE</u>. Enter date on which the MPA work sheet is prepared.
7	<u>REVISION NO./DATE</u>. Enter revision number and date when work sheet is changed after initial preparation. (Note: Place vertical bar next to each change in the appropriate block.)
8	<u>FAILURE MODE</u>. Enter key words from Block 10, FMEA Work Sheet, Figure 5-5. The A, B, C and D sub-blocks will accommodate up to four different failure modes for each MSI, and these all correspond to the four in Block 9 and in each of the 21 logic questions.

Block	
9	CLASSIFICATION. Enter classification of failure from Block 10 of FMEA, Figure 5-5.
10 through 51	These blocks contain the answers to each of the logic questions as they are applied to each failure mode identified in Block 8 (A, B, C, or D) along with certain pertinent facts necessary to attaining the best maintenance allocation. The analyst should answer only those questions that are applicable to a specific failure mode by following the flow indicated on the decision logic diagram. No specific failure mode will require the answering of all twenty-one questions.

5.2.3.1 Detailed Instructions for Each Logic Question

Question No. 1. Is the Maintenance Significant Item (MSI) a component that is redundant in its application or part of a redundant system or network?

See Figure 5-10 to identify the input data necessary to answer this question.

A YES answer to this question means that if the MSI is allowed to fail in the mode under consideration the system continues to function in a normal manner through a duplicate item and the mission is carried out to a satisfactory conclusion.

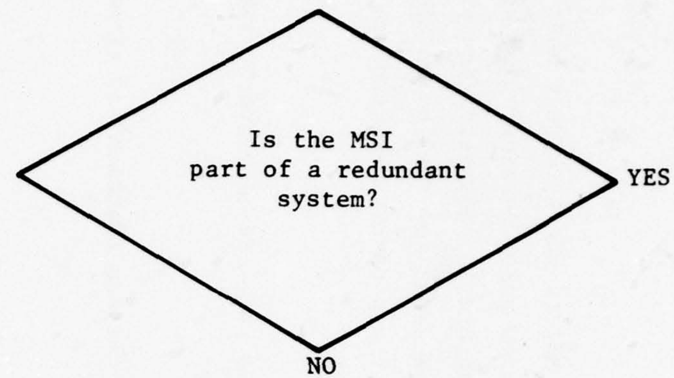
Check YES and identify in Block 10 the redundant function provided by the MSI.

Maintenance Significant Item Identification

- Part Number
- Part Nomenclature
- Next Assembly/System Location
- Part Function/Relationship
- Number of Parts in Major End Item
- Major End Item Function

Reference

- Work Sheet: Figure 5-5 (FMEA)
- Technical Manuals
- Engineering Drawings
- Generation Breakdown



Explanations:

Redundant System: Dual independent paths/operations by which a single function will be completed. (Example: Signaling device; green band voltmeter coupled with a voltage-level-sensing indicator light. Both give visual indication of an available level of voltage.)

Figure 5-10. Inputs Required To Answer Question No. 1.

A NO answer indicates that the MSI is the sole unit having its individual function in the application under consideration and a failure of the item results in fault/failure in the system/equipment in which it is installed. Check NO and enter any remarks in Blocks 10 and 11 that aides in the evaluation of the potential maintenance process for inclusion in the maintenance program.

Question No. 2. Is the function which is affected by the failure mode hidden from the operator/crew?

An MSI is considered to have a "hidden function" if either of the following exists:

1 The MSI has a function which is normally active whenever the system is used, but there is no indication to the operator/crew when that function ceases to perform.

2 The MSI has a function which is normally inactive and there is no prior indication to the operator/crew that the function will not perform when called upon. The demand for active performance could follow another failure, and the demand may be activated automatically or manually.

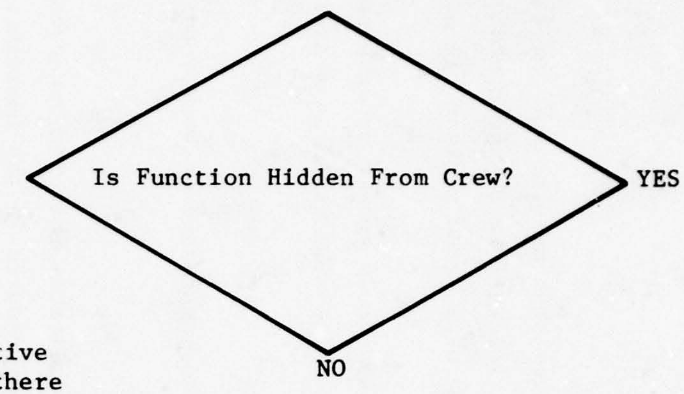
The functional description contained in Block 8 of the FMEA Work Sheet and the explanations given in Figure 5-11 are the basis on which the answer to this question is generated.

If the answer is YES, then proceed to Question No. 10 to determine if there is a maintenance and/or test procedure which ensures a high probability that the hidden function operates as designed. Enter YES and identify in Block 12 the hidden function.

Maintenance Significant Item Identification

Part Number
Part Nomenclature
Part Function/Relationship
Number of Parts In Major End Item
Major End Item Function

Reference
Work Sheet: Figure 5-5 (FMEA)
Technical Manuals



Explanations:

Hidden Function:

a) A function which is normally active whenever system is in use, but there is no indication when the function ceases.

b) A normally inactive function and there is no prior indication to the operator/crew that the function will not perform when called upon.

Figure 5-11. Inputs Required To Answer Question No. 2.

If the anwer is NO, it indicates that evidence of the failure or potential failure of a function is perciptible to the operator/crew during normal operations. Enter NO plus "crew monitor" in Block 12.

Question No. 3. Does the failure mode result in an abort, a mission failure or a safety hazard which results in personnel injury or equipment damage?

See Figure 5-12 to identify the input data necessary to answer this question.

A YES anwer to this question indicates that the occurrence of the failure mode under consideration results in the immediate suspension in the operation of the system/equipment for such a period of time that it prevents the successful completion of the mission. A YES answer to this question also indicates that the occurrence of the failure mode under consideration produces such results that injury of personnel or damage to equipment is likely or possible. In either of these cases, enter YES and identify in Block 14 the failed state that results in abortion, personnel injury or equipment damage, and identify the expected results, In Block 15, enter statement as to whether the abortion, personnel injury or equipment damage is a direct or indirect result of the failure.

A NO answer indicates that a failure in the mode under consideration, while possibly affecting the efficiency of the operation, is not sufficiently serious in nature to require curtailment of the mission, result in personnel injury or equipment damage.

Enter any additional remarks in Block 15 that aids in the evaluation of the potential maintenance process for inclusion in the maintenance program.

Maintenance Significant Item Identification

Part Number
Part Nomenclature
System Function
Part Function/Relationship

Reference
Work Sheet: Figure 5-5 (FMEA)
U.S. Army Safety Regulation (As Applicable)
Organization SOPs
Missile Countdown and emergency procedures

Explanations:

Personnel and Equipment Safety Hazard -

Any degradation or malfunction that could result in injury to personnel or damage to the system/equipment.

Mission Abort -

Results of a malfunction, failure or maintenance task which prevents the successful completion of the mission.

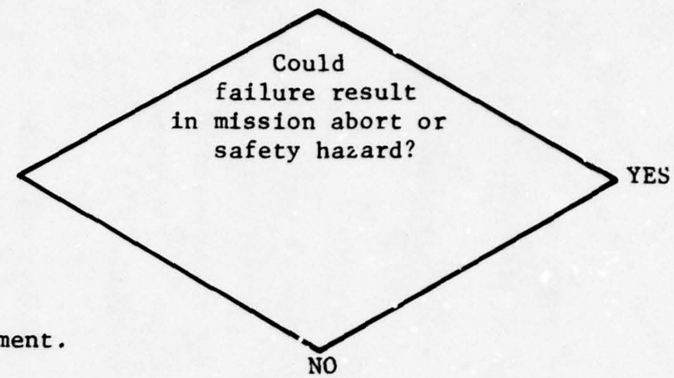


Figure 5-12. Inputs Required To Answer Question No. 3.

Question No. 4. Does a failure in the mode under consideration result in a secondary failure of a critical nature?

See Figure 5-13 to identify the input data necessary to answer this question.

A YES answer to this question indicates that while a failure in the mode under consideration is not in itself critical if left uncorrected it triggers a secondary failure which could be of a critical nature. Check YES and identify in Block 16 the nature of the secondary failure and its critical implications in Block 17.

A NO answer indicates that the failure mode under consideration in no way produces a chain reaction resulting in a critical failure. Check NO plus any comment in Block 16.

Question No. 5. Are there maintenance, test, or inspection procedures that can be performed to detect a deterioration of reliability in the failure mode under consideration?

See Figure 5-14 to identify the input data necessary to answer this question.

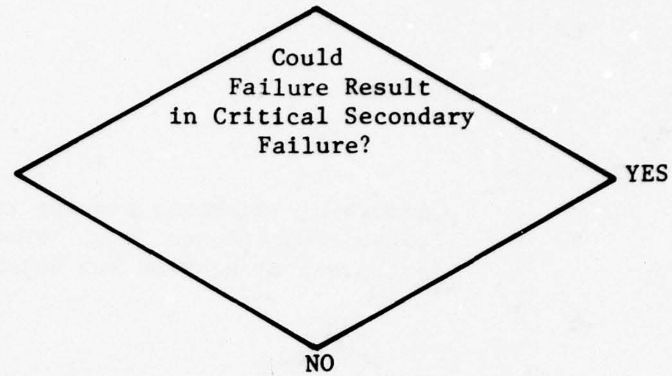
A YES answer to this question indicates that there exists maintenance or test or inspection procedure(s) that have the potential for reliably detecting incipient conditions before a failure occurs. Check YES and identify in Block 18 the specific maintenance, test, inspection procedure(s) that can be used to detect the impending failure. Also, identify the indicator of the impending failure in Block 19.

Maintenance Significant Item Identification

Part Number
Part Nomenclature
System Function
Part Function/Relationship

Reference
Work Sheet: Figure 5-5 (FMEA)
Technical Manuals
Procedures Manuals

Explanations:

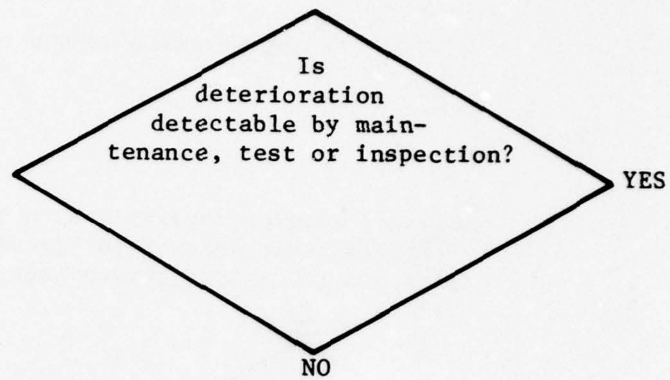


Critical Secondary Failure - A failure in which the degradation/malfunction of one part, although not critical in itself, will cause other part(s) to degrade and/or malfunction in a critical system function.

Figure 5-13. Inputs Required To Answer Question No. 4.

Maintenance Significant Item Identification

Part Number
Part Nomenclature
Part Failure Mode
Part Deterioration Detection Method
Deterioration Detection Probability
Test Equipment Required



Reference
Work Sheet: Figure 5-6 (FADALA)
Technical and Procedures Manuals

Explanations:

Deterioration Detection Method - Testing and/or inspecting the measurable quantities such as wear, resistence, color change temperature, etc., that will signal adverse change(s) in expected performance.

Figure 5-14. Inputs Required To Answer Question No. 5.

Examples of entries that will appear in Blocks 18 and 19 are:

(Block 18)	(Block 19)
BIT	Go-No-Go
DIAGNOSTIC INSTRUMENTATION	Variance from Norm
FUNCTIONAL CHECK (TEST)	Operators Instruments - Process variable, Improper responses, Variance from norm
VISUAL INSPECTION	Abnormal condition, i.e., damage, leaks, activity/inactivity, etc.
SOUND INSPECTION	Abnormal sounds/no sounds
TOUCH/FEEL	Abnormal vibrations Improper responses
TEST/MEASUREMENTS	Variance from normal numerical values
DYNAMIC TEST	Proof/recertification loads - failure to meet standards
PERFORMANCE VERIFICATION	At rated loads - degraded performance
AGE CHECK	Excess statistical life expectancy, fatigue factor
STATIC TEST	Proof/recertification loads - failure to meet standards
POWER RATING TEST	Variance from norm
ENVIRONMENT CHECK	Undesirable effects
DISMANTLE INSPECTION	Excessive/abnormal wear
DUTY CYCLE CHECK	Extensive periods of activity/ inactivity

(Block 18)	(Block 19)
SPECTROGRAPHIC ANALYSIS	Abnormal concentration of chemicals/materials
X-RAY	Defects (cracks, flaws, etc.)

If the answer is NO, there are no effective methods by which maintenance personnel can determine an incipient condition, therefore, any maintenance, testing or inspection is useless and no such task is to be scheduled. The item is included in condition monitoring. Check NO and enter "CONDITION MONITORING" in Block 18. Notes for specific condition monitoring are entered in Block 19.

Question No. 6. Is the impending failure/malfunction detectable by crew during normal equipment operation? (NOTE: "crew" is inclusive of any operator or operators.)

See Figure 5-15 to identify the input data necessary to answer this question.

A YES answer to this question means that it is convenient and expected for the crew to monitor conditions during system operation whereby an incipient condition can be determined to be present <u>prior</u> to the occurrence of the failure. Therefore, methods must be identified whereby the operator/crew can monitor for a deteriorating condition along with his/their other normal duties. Check YES and identify in Block 20 the procedure(s) by which the operator/crew can detect the incipient condition. Also, identify the indicator of the impending failure in Block 21.

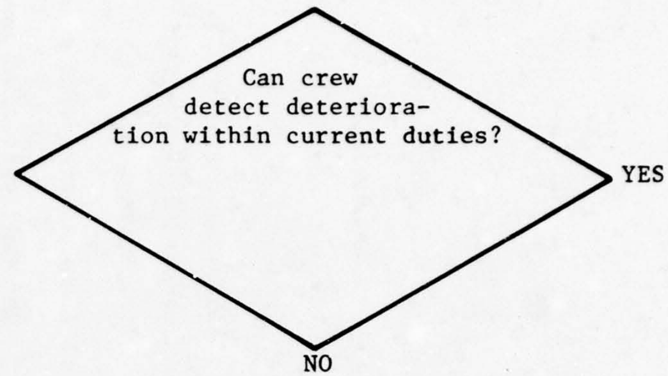
Examples of entries that will appear in Blocks 20 and 21 if the answer is YES are:

Maintenance Significant Item Identification

- Part Number
- Part Nomenclature
- Part Failure Mode
- Part Deterioration Detection Method
- Deterioration Detection Probability

Reference

- Work Sheet - Figure 5-6 (FADALA)
- Technical and Procedures Manuals
- Organization SOPs



Explanations:

Detection During Normal Operations - There is a means available to the operator/crew to detect deterioration of an item or system without diverting from the currently established operating procedures. (Examples: A light indicating oil is low, warning horns to indicate overheating, etc.)

Figure 5-15. Inputs Required To Answer Question No. 6.

(Block 20)	(Block 21)
TEST BITE	Go-No-Go
DIAGNOSTIC INSTRUMENTATION	Variance from norm
FUNCTIONAL CHECK	Process variable
(Operator Instruments)	Improper responses, Variance from norm
VISUAL INSPECTION	Abnormal condition, i.e., damage, leaks, activity, inactivity, etc.
SOUND INSPECTION	Abnormal sounds/no sounds
TOUCH/FEEL	Abnormal vibrations, movement Improper responses

If the answer is NO, there are no convenient means now available by which the operator/crew can detect a deteriorating condition prior to a failure occurrence. Check NO plus consider the following note.

IF the answer is NO, consideration is given to the possibility of revising the duties of the operator/crew to provide for monitoring the system/equipment for deterioration of reliability. This requires that the operator/crew perform such tasks as periodic testing or inspections. If this consideration results in a positive conclusion enter "REVISE DUTIES" in Block 20 and identify in Block 21 the method by which the operator/crew can monitor the system/equipment for impending failure.

Question No. 7. Can the crew (operator included) detect a failure within their current duties? This question is a follow-on to Question No. 6 but it addresses an actually failed condition rather than an impending failure. A possible example is a bad printed circuit (PC) card. The built-in-test-equipment (BITE) identifies the failure to the crew, but does not indicate an incipient failing condition.

See Figure 5-16 to identify the input data necessary to answer this question.

A YES answer to this question means that it is reasonable to expect the crew to become aware of a failure at its time of occurrence without any previous perception of deterioration. Therefore the method(s) are to be identified whereby the failure is indicated to the crew in consonance with normal duties. Check YES and identify in Block 22 the failure detection method. Also enter in Block 23 the failure indicator.

If the answer is NO, there is no available means for the crew to perceive that the failure has occurred. Check NO. Since use of the RCM logic process has determined that failure could be critical, the function is not redundant, and the crew cannot detect deterioration or failure, enter in Block 22 "MAINTENANCE INDICATED" and also enter in Block 23 other pertinent considerations.

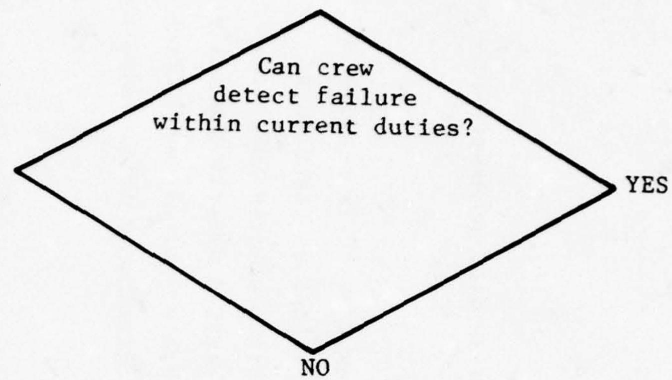
As in Question No. 6, it is still possible that the crew duties can be revised to provide crew detection capability although it is more probable that some maintenance action will be required.

Question No. 8. Is preventive maintenance more economical than corrective maintenance? This question is applied to all failure modes which are not classified as critical. Economics are not a considera-tion where safety or mission success is concerned or when the function is hidden from the operator/crew.

Question No. 8 requires the engineer to determine the effects and consequences in the event of a failure occur, along with the cost of maintenance and support resources for performing both corrective and preventive maintenance.

Maintenance Significant Item Identification

Part Number
Part Nomenclature
Part Failure Mode
Part Failure Detection Method
Failure Detection Probability



Reference

Work Sheet - Figure 5-6 (FADALA)
Technical and Procedures Manuals
Organization SOPs

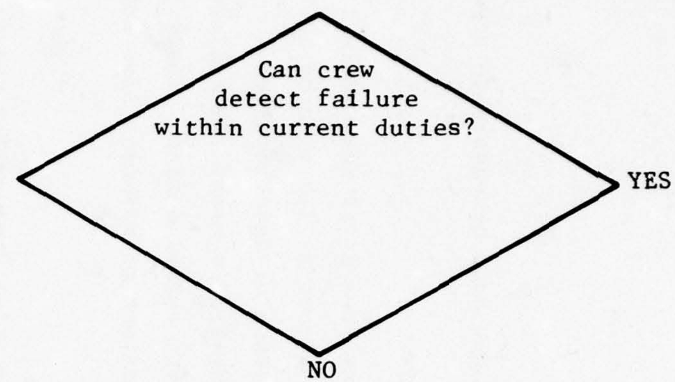
Explanation:

Detection During Normal Operations - There is a means available to the crew to detect the failure of an item or system without diverting from the currently established operating procedures. (Possible Examples: Printed circuit card with BITE.)

Figure 5-16. Inputs Required to Answer Question No. 7.

Maintenance Significant Item Identification

Part Number
Part Nomenclature
Part Failure Mode
Part Failure Detection Method
Failure Detection Probability



Reference
Work Sheet - Figure 5-6 (FADALA)
Technical and Procedures Manuals
Organization SOPs

Explanation:

Detection During Normal Operations - There is a means available to the crew to detect the failure of an item or system without diverting from the currently established operating procedures. (Possible Examples: Printed circuit card with BITE.)

Figure 5-16. Inputs Required to Answer Question No. 7.

The evaluation will conclude first, whether the consequences of a failure can be tolerated, and second, whether preventive or corrective maintenance is the most economical.

See Figure 5-17 to identify the input data necessary to answer this question.

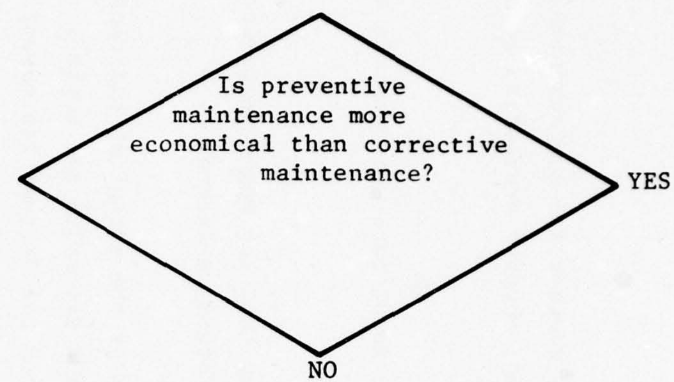
To answer this question requires that the engineer perform a tradeoff study of the costs of performing maintenance.

The engineer must consider each of the potential maintenance tasks (preventive and corrective) and determine the expenditures for maintenance and support resources and the frequencies associated therewith. In addition, he must determine what influence each potential maintenance task has on the mission success probability. In trading the maintenance tasks to determine the economics, only those elements directly affected need to be considered. A tradeoff check list, Figure 5-18 provides a means of determining which elements are relative to the decision.

For each check in the impact column a cost must be provided. The totals of each column will be compared to determine the delta cost associated with each potential maintenance task. In addition, two non-cost items must be considered, these are, impact on mission success in terms of probability of mission aborts and effect on reliability. The combination of data should be an indication as to the economic worthiness of the task. For example, if the dollar impact indicates that the preventive maintenance task is cost effective, but if it does not restore the inherent reliability or decrease probability of mission failure the task would be undesirable.

Maintenance Significant Item Identification

- Part Number
- Part Nomenclature
- Part Failure Mode
- Part Failure History
- Current Maintenance Costs
- RCM Maintenance Costs



Reference

- Work Sheet: Figure 5-5 (FMEA)
- Failure Reports & Replacement Records
- Preventive Maintenance Schedule
- Manpower and Cost Data Records
- Technical Manuals
- Supply Support/Provisioning Records
- Maintenance Directives
- Task Orders & Work Records
- Army Forces Cost Planning Handbook

Explanations:

Comparative analysis of historical data, on preventive maintenance and corrective maintenance related to the item in question is required to determine which is/will be more economical to the army system.

Figure 5-17. Inputs Required To Answer Question No. 8.

	PREVENTIVE MAINTENANCE			CORRECTIVE MAINTENANCE	
LOGISTICS SUPPORT COST	IMPACT	REPAIR COST	OVERHAUL COST		
SUPPORT AND TEST EQUIPMENT	☐	$ ______	$ ______	☐	$ ______
TRANSPORTATION	☐	______	______	☐	______
TRAINING	☐	______	______	☐	______
FACILITIES	☐	______	______	☐	______
PERSONNEL	☐	______	______	☐	______
MATERIALS	☐	______	______	☐	______
PIECE-PART SPARES	☐	______	______	☐	______
SPARES	☐	______	______	☐	______
TOTAL	....	$ ______	$ ______	....	$ ______
MISSION ABORT PROBABILITY	☐	%	%	☐	%
EFFECT ON RELIABILITY	☐	%	%	☐	%

Figure 5-18. Tradeoff Check List

If the engineer concludes, as a result of the trade-off, that the consequences of a failure are intolerable or that preventive maintained is the least costly he checks YES and summarizes his conclusion in Block 24.

If on the other hand it is the conclusion that the consequence of the failure can be tolerated and that corrective maintenance is the least costly in terms of maintenance and support resources, NO is checked.

Question No. 9. Having detected an incipient or failed condition, does the operator/crew possess the capability of performing on-the-spot maintenance to correct the fault?

See Figure 5-19 to identify the data necessary to answer this question.

A YES answer to this question indicates the operator/crew possess, at the operational level, the tools, test equipments and spare parts that may be required to correct an incipient condition. Also, it indicates that the necessary maintenance to be accomplished without major disassembly of the system/equipment and all effort is accomplished with minimum interruption to the system/equipment operation. Check YES and in Block 26 summarize the maintenance procedure.

A NO answer indicates that the operator/crew does not possess the essentials to perform maintenance on-the-spot. Check NO.

Question No. 10. Is deterioration detectable by maintenance, test/inspection?

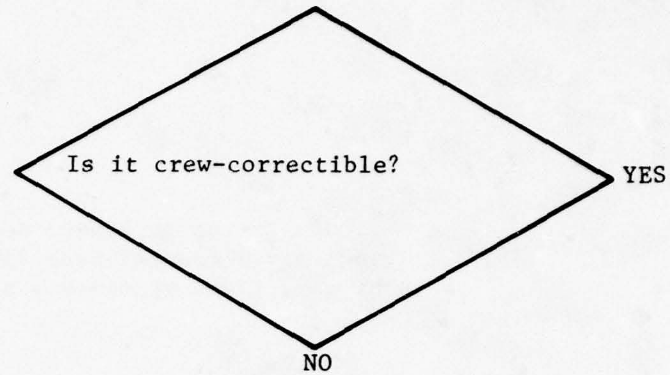
See Figure 5-20 to identify the data necessary to answer this question.

Maintenance Significant Item Identification

- Part Number
- Part Nomenclature
- Part Fault Detection & Location Methods
- Part Failure History

Reference

- Work Sheet - Figure 5-5 (FADALA)
- Failure Reports & Replacement
- Technical Manuals
- Maintenance Directives
- Organization SOPs
- Maintenance Allocation Charts



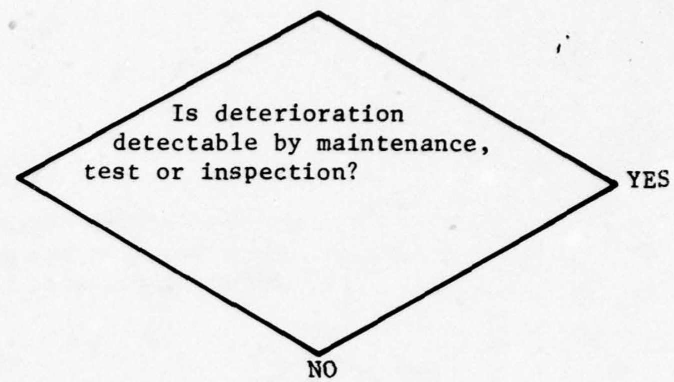
Explanations:

Historical Records and/or maintenance skills, access to required tools and test equipment must show operator/crew capability to perform the required tasks without impairing normal operating procedures and without affecting mission success.

Figure 5-19. Inputs Required To Answer Question No. 9.

Maintenance Significant Item Identification

Part Number
Part Nomenclature
Part Failure Mode
Part Deterioration Detection Method
Deterioration Detection Probability
Test Equipment Required



Reference
Work Sheet: Figure 5-6 (FADALA)
Technical & Procedures Manuals

Explanations:

Deterioration of Reliability - Does the item/system have measurable quantities such as wear, resistence, color temperature, etc., that indicate potential adverse change(s) in its expected performance.

Figure 5-20. Inputs Required To Answer Question No. 10.

In order to answer this question the engineer must have, in addition to a knowledge of the maintenance methods and procedures presently employed on the system/equipment under evaluation, a knowledge of other available methods/procedures, including those which are considered state-of-the-art. Also, he must be able to relate these methods/procedures and their application to the system/equipment he is evaluating.

If the answer is YES, this means that methods/procedures are available by which a deterioration of reliability can be identified and that they are applicable to the failure mode under consideration check YES and in Block 28 enter a brief description of all methods/procedures identified in Block 29. (See listing under question No. 5 for example of entries in Block 29.)

A NO answer indicates that no methods exist by which a deteriorating condition is isolated.

Question No. 11. Is failure detectable by maintenance test/inspection?

See Figure 5-21 to identify the data necessary to answer this question.

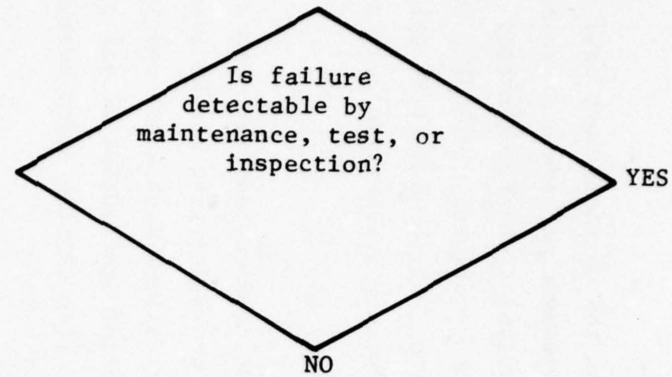
This is a follow-on to Question No. 10 but it addresses a failed condition rather than an impending failure. A YES answer to this question means that the failed condition is detectable by maintenance personnel and the method identifiable. Check YES and enter in Block 30 the failure detection method, and in Block 31 enter the failure indicator. (Block 30 and 31 entries would be similar to those given for Question No. 5.)

A NO answer indicates that the MSI failure mode is not detectable by maintenance personnel at the organizational level.

Maintenance Significant Item Identification

- Part Number
- Part Nomenclature
- Part Failure Mode
- Failure Detection Method
- Failure Detection Probability
- Test Equipment Required

Reference
- Work Sheets: Figure 5-6 (FADALA)
- Technical & Procedures Manuals



Explanation:

Failure Detection - Does the item/system have measurable factors to determine that a failure has occurred causing item/system performance to be less than minimum acceptable?

Figure 21. Inputs Required To Answer Question No. 11.

Check NO and note in Block 30 that this MSI failure mode requires special attention. Possible actions recommended could be entered in Block 31.

Question No. 12. Is failure a result of age or usage?

See Figure 5-22 to identify the data on which the answer to this question is generated.

A YES answer to this question indicates that the MSI is either a limited life component or that the failure rate is directly related to an operating and/or calendar time period. Check YES and identify in Block 32 the limiting circumstance. Enter "HARDTIME MAINTENANCE" in Block 33.

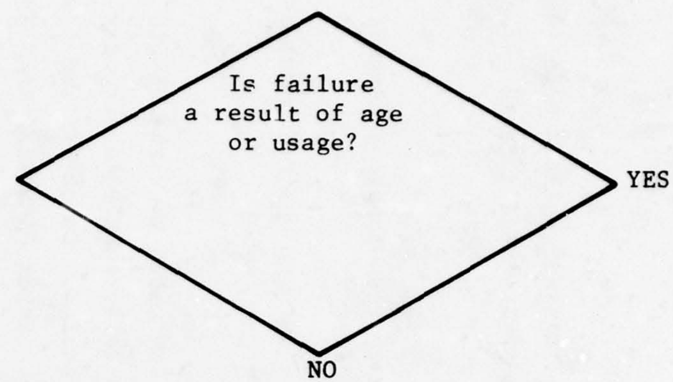
If the answer is NO, this means that no precise failure pattern can be identified, therefore, failures are considered to be random in their occurrence. Check NO and in Block 32 enter "Redesign to be Recommended". During the time the redesign is being considered the MSI must be carried as a condition monitoring task. Enter "CONDITION MONITORING, RESTRICT USAGE" in Block 33. After the redesign has been accomplished the MSI must be reevaluated to determine what changes in the maintenanace task are necessary as a result of the redesign effort.

Question No. 13. Does the maintenance data substantiate the scheduling of the potential preventive maintenance task, if so, at what frequency?

It will be necessary for the engineer to examine the maintenance records to determine if the historical data indicates that scheduling of the maintenance is warranted, if so, what is the desired interval. The engineer should analyze failure rates and trends, determining if possible, the source of the failure along with any significant

Maintenance Significant Item Identification

- Part Number
- Part Nomenclature
- Part Function/Relationship
- Part Failure Mode
- Part Failure Detection Method
- Part Deterioration Detection Method



Reference

- Work Sheet: Figure 5-5 (FMEA)
- Work Sheet: Figure 5-6 (FADALA)
- Eng/Vendor Test Data
- Historical Replacement Data
- Part Reliability Analysis

Explanations:

Age/Use - Refers to wearout components where time/use of the component causes a predictable wear/deterioration.

Figure 5-22. Input Required To Answer Question No. 12.

maintenance requirements. Should no clear cut indication be found as to what the maintenance task frequency should be, then the engineer should establish the maintenance requirement through the application of knowledgeable judgment.

See Figure 5-23 to identify the data necessary to answer this question.

A YES answer means that the historical maintenance data or expert opinion would indicate that the maintenance task associated with the failure mode under consideration should be performed on a periodic basis. Check YES and enter frequency which maintenance task should be performed in Block 34.

A NO answer means that the historical maintenance data or expert opinion would indicate no periodic maintenance task is advisable. Check NO.

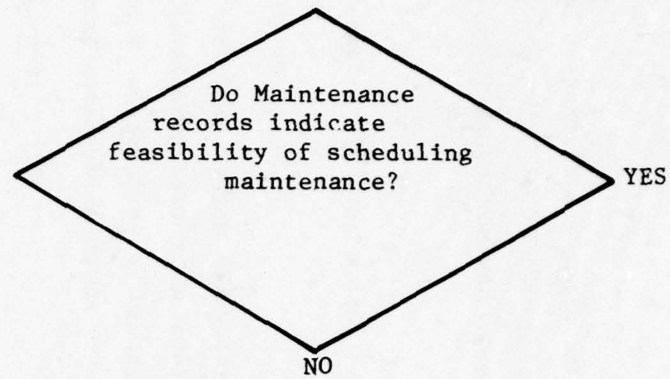
Question No. 14. Do safety or reliability reasons indicate scheduling of maintenance?

See Figure 5-24 for data necessary to answer this question.

Certain types of equipment/systems have characteristics that require scheduling maintenance in order to retain inherent reliability or protect the safety of personnel/equipment even though their deterioration might be monitorable by a crew. Technical publications and administrative directives usually specify this type of maintenance, test or inspection at recommended intervals to protect safety/reliability features. Therefore, even though the decision logic may suggest condition monitoring, such equipment must be allocated to on condition maintenance.

Maintenance Significant Item Identification

Part Number
Part Nomenclature
Part Failure History
Part Maintenance History
Part MTBF, MTTR
Part Function/Relationship



Reference
Failure Reports & Replacement Records
Manpower & Repair Costs Data
Supply Support & Prov. Records
Army Forces Cost Planning Handbook

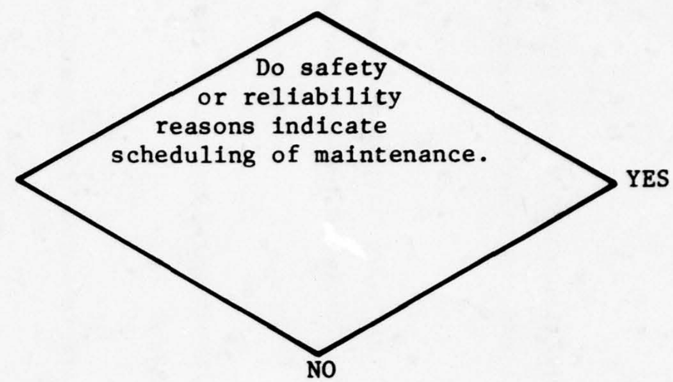
Explanations:

In an analysis of the maintenance records, determination must be made as to whether preventive maintenance will diminish the number of failures through detection of deterioration prior to failure, or in some way increase the availability of the system.

Figure 5-23. Inputs Required To Answer Question No. 13.

Maintenance Significant Item Identification

Part Number
Part Nomenclature
Part Failure History
Part Replacement History
Part MTBF, MTTR
Part Function/Relationship



Reference
Safety analysis
FMECA (If available) or Work Sheet 5-5 (FMEA)
Failure Reports and Replacement Records
Maintenance Directives
Technical Manuals
Work Sheet 5-6 (FADALA)

Explanations:

For purpose of safety of personnel/equipment or to retain inherent reliability in a critical item it may be advisable to schedule maintenance even though the logic might not so indicate. Also there may be directives on hand that require periodic checkups.

Figure 5-24. Input Required To Answer Question No. 14.

If the MSI failure mode fits this situation, answer YES and enter in Block 36 the required maintenance and the scheduled interval in Block 37.

A NO answer would indicate that there are no compelling reasons to indicate scheduling maintenanace (and there are probably no administrative requirements for same). Check No.

Question No. 15. Are their any equipment limitations that indicate unique maintenance programming?

See Figure 5-25 for data necessary to answer this question.

Unique maintenance program is defined as an MSI failure mode that requires more than one maintenance task classification. For example, an aircraft engine lubrication system usually has an oil change after a period of usage hours, but in between these changes, an oil sample is taken and analyzed to assess it condition. The oil change is a hardtime task whereas the oil analysis is an on condition inspection.

For cases of this type, check YES and indicate in Block 38 the two classes of maintenance tasks . In Block 39 enter the tasks required.

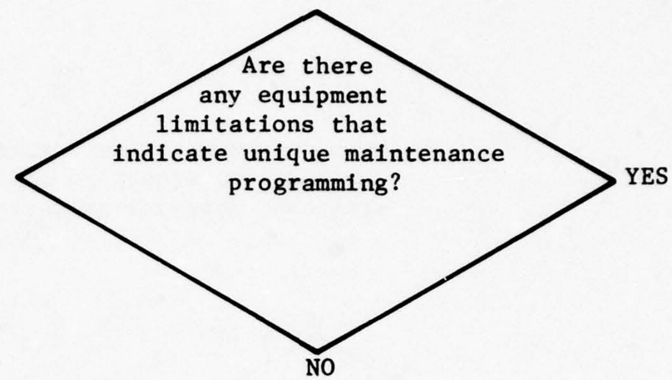
A NO answer means that the equipment can be properly maintained with on condition maintenance. Check NO and enter "ON CONDITION" in Block 38. In Block 39 identify the type of test/inspection and interval.

Question No. 16. Are there any equipment limitations that indicate unique maintenance programming?

See Figure 5-26 for data necessary to answer this question.

Maintenance Significant Item Identification

- Part Number
- Part Nomenclature
- Part Failure History
- Part Replacement History
- Part MTBF, MTTR
- Part Function/Relationship



Reference

- FMECA (If available) or Work Sheet 5-5 (FMEA)
- Failure Reports and Replacement Records
- Maintenance Directives
- Technical Manuals
- Work Sheet 5-6 (FADALA)

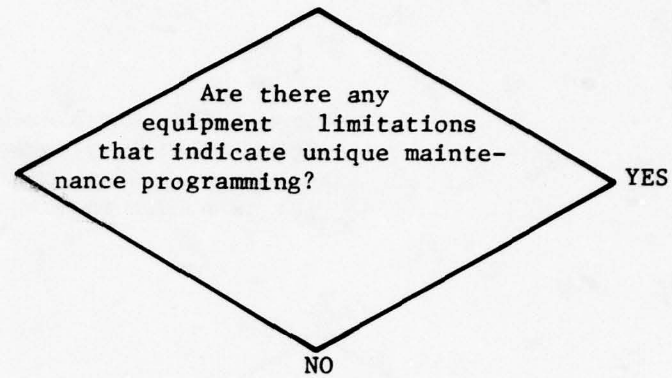
Explanations:

Some items require periodic, hardtime replacement of the item or one of its components, but between these events, periodic inspections or tests are necessary to detect unusual wear or deterioration. If so, the item should be given unique handling by establishing both on condition maintenance and hardtime replacement.

Figure 5-25. Input Required To Answer Question No. 15.

Maintenance Significant Item Identification

Part Number
Part Nomenclature
Part Failure History
Part Replacement History
Part MTBF, MTTR
Part Function/Relationship



Reference
FMECA (If available) or Work Sheet 5-5 (FMEA)
Failure Reports and Replacement Records
Maintenance Directives
Technical Manuals
Work Sheet 5-6 (FADALA)

Explanations:

It is possible for an item to require hardtime replacement at periodic intervals even though condition monitoring is also possible. This type of double maintenance may be advisable in specific cases in order to prevent aborting an otherwise successful mission.

Figure 5-26. Input Required To Answer Question No. 16.

Obviously, this question is identical to Question No. 15; however, the decision logic path to reach No. 16 is different because of the characteristics of the MSI failure mode under consideration. Also, the maintenance task classifications resulting from either answer are different. A YES answer here means that the MSI requires both hard-time and condition monitoring, and an example of this might be a mercury battery that is replaceable by the operator/crew. Even though the spare battery is available to the crew, it would be wise to replace on hardtime the battery which has been in use for 100 hours or so in order that at start of the mission, two good batteries are on hand rather than one good spare and one that almost certainly will give out during the mission.

If such a situation exists, check YES and enter in Block 40 the two classes of maintenance tasks, and identify both in Block 41.

A NO answer means that the equipment can be properly maintained with condition monitoring alone. Check NO and enter "CONDITION MONITORING" in Block 40. Block 41 should show the method by which the deterioration/failure condition is monitored by the operator/crew.

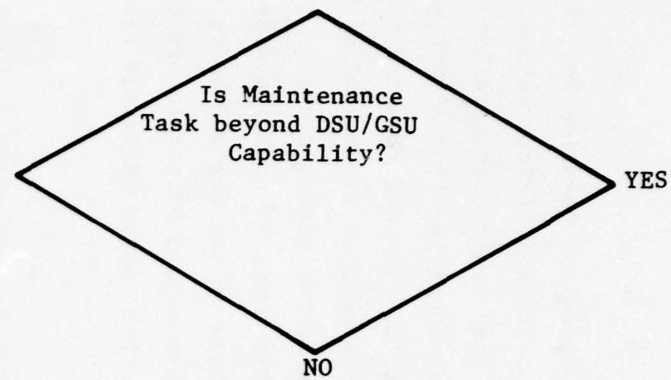
Question No. 17. Is the maintenance task beyond the DSU/GSU capability?

See Figure 5-27 to identify the data necessary to answer this question.

A YES answer to this question indicates that the preventive maintenance task is of such a magnitude that it requires skills, tools, test equipment, facilities, etc., which are not available at the DSU/GSU organizational level. An example of such a PM task is the scheduled overhaul of a major component such as an aircraft engine or a helicopter rotor gear box. Enter YES and enter "Depot Task" in Block 42. The entry in Block 43 should show the reason for assigning

Maintenance Significant Item Identification

Part Number and Nomenclature
Identification of Maintenance Tasks to be performed



Reference
- Maintenance Allocation Charts
- Maintenance Directives
- Organization TO&E
- DSU/GSU TO&E

Explanations:

Equipment, personnel, facility requirements are compared against the capabilities and equipment to be found at the user maintenance organizational level and the DSU/GSU organization charged with the responsibility to support the system/equipment.

Figure 5-27. Inputs Required To Answer Question No. 17.

the work to depot.

A NO answer would indicate that the PM task could be performed by either the user's maintenance organization or by the DSU/GSU organization. Enter NO.

Question No. 18. Will the scheduled maintenance tasks require the system/equipment to be off-line (red-lined) for more than ____ hours?

See Figure 5-28 to identify the data necessary to answer this question.

A YES answer to this question would indicate that the performance of maintenance tasks is rather extensive, requiring possible disassembly, and would consume more than a predefined number of hours to complete. The extensiveness of the tasks and time duration make it impractical for maintenance to be performed at the organizational level. Check YES and enter "OFF LINE" in Block 44, and the estimated maintenance time in Block 45.

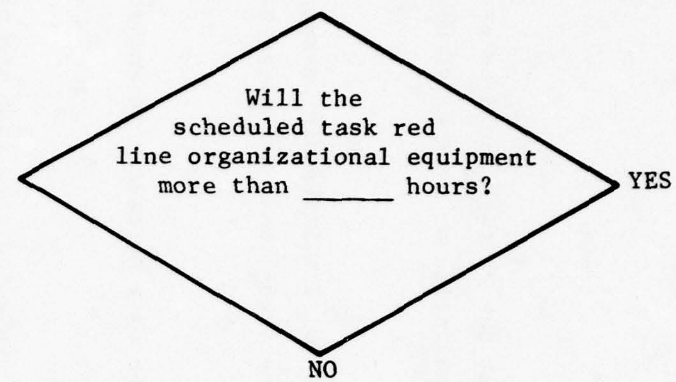
A NO answer indicates that the maintenance tasks are relatively minor and are within the operational organization's capability to accomplish. Check NO and indicate estimated time for the maintenance in Block 44.

Question No. 19. Does the scheduled maintenance tasks require tools, test equipment or skills which are unrealistic for on-line usage?

See Figure 5-29 for the data required to generate an answer to this question.

Maintenance Significant Item Identification

Part Number & Nomenclature
Identification of Maintenance Tasks to be performed
Mean Time to repair of item/system



Reference
- Historical Maintenance Data Records
- Mission Status of System/Equipment
- Environmental Conditions effects on task duration
- Mission Window (type of alert)
- Maintenance Allocation Charts
- Maintenance Directives
- Organization SOPs

Explanations:

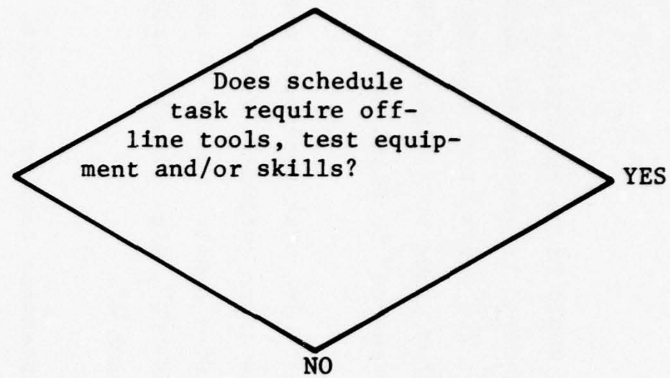
Mission status of system/equipment pertains to the purpose of the system/equipment, i.e., tactical, troop support defensive, etc. Mission window pertains to the required reaction time. "_____ hours" is for insertion of the number of hours the equipment can be red lined without interfering with the mission window.

Figure 5-28. Inputs Required To Answer Question No. 18.

Maintenance Significant Item Identification

Part Number and Nomenclature
Identification of task to be performed

Reference
Maintenance Allocation Charts
Maintenance Directives
Historical Maintenance Records
Tools and test equipment required
to accomplish task
Manpower required
Facility Interfaces
Organization SOPs



Explanation:

Off-line tools, test equipment and skills - in order to perform the scheduled tasks, the system/equipment may have to be moved to where there are tools, test equipment, and skills not normal to organizational maintenance. (Example: Fixed computerized diagnostic test stations, large hydraulic pressure test units, dynamometers, jacks, lifts, etc.)

Figure 5-29. Inputs Required To Answer Question No. 19.

A YES answer indicates that it would be unrealistic to provide the tools, test equipment or skills required to perform the maintenance tasks at the organizational level. The tools, test equipment and skills required are more suitable for usage at a higher echelon. Check YES and enter "off-line maintenance" in Block 46.

A NO answer indicates that the tools, test equipment and skills could reasonably be provided at the organizational level without burdening the battalion with excessive assets. Check NO and enter in Block 46 "ORGANIZATIONAL MAINTENANCE", plus identify tools, test equipment or skills required in Block 47.

Question NO. 20. Will the maintenance task prove vital to maintaining operational readiness?

See Figure 5-30 for the data required to generate an answer to this question.

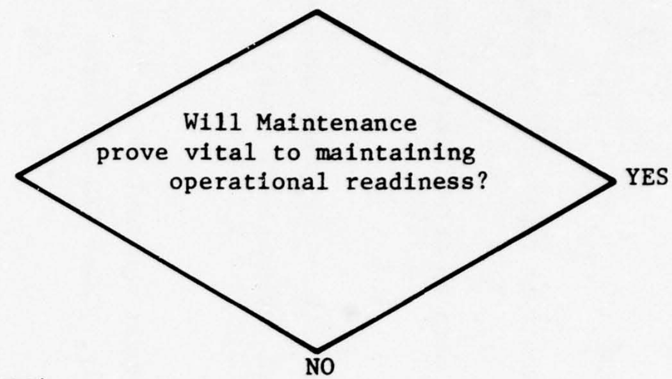
Consideration must be given to the number of maintenance tasks assigned the system/equipment user organization. Overburdening the organizational maintenance personnel with maintenance tasks restricts the performance of more important duties that could directly contribute to increased combat efficiency. A YES answer indicates that the maintenance task has been evaluated and it is vital to maintaining operational readiness of the system/equipment, or that there are other considerations which provide a benefit for performing maintenance at the organizational level. Enter YES.

A NO answer indicates that the maintenance task is not vital to maintaining operational readiness and there is no distinct advantages to performing the maintenance task at the organizational level. Enter NO.

Maintenance Significant Item Identification

Part Number & Nomenclature
Identification of Maintenance task to be performed

Reference
Maintenance Allocation Chart



Explanation:

Overburdening the using organization with maintenance task has an inverse relationship to combat effeciency in most cases and should be avoided. However retention of operational readiness makes it mandatory to retain certain tasks at the operational level.

Figure 5-30. Input Required To Answer Question No. 20.

Question No. 21. Is the removed item repairable beyond DSU/GSU?

See Figure 5-31 for the input data to be utilized to answer this question.

Each item removed from a major item or equipment must be appraised as to its repair/overhaul potential and location by evaluation against this question.

A YES answer indicates that repair/overhaul is possible other than at DSU/GSU (usually at depot level). Check YES and enter "DEPOT" in Block 50.

A NO answer indicates that repair/overhaul of the item(s) is feasible at DSU/GSU level. Check NO and enter in Block 50 the proposed location for repair of the item.

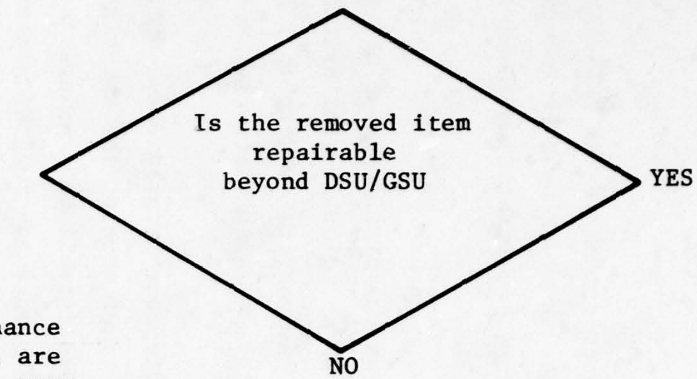
With the completion of the MPA work sheet containing the logic questions, the engineer will analyze and evaluate its contents to determine effectiveness or noneffectiveness of the potential maintenance task in order to include in the maintenance plan only those items necessary to develop valid scheduled maintenance requirements for the system/equipment. The engineer will exclude from the maintenance plan those existing and/or potential requirements which increase overall maintenance/support resource expenditures without a corresponding increase in reliability and safety protection.

To perform an effective analysis and evaluation it is necessary for the engineer to consider all possible parameters such as frequency of failure, recommended maintenance intervals, tolerability of accepting an "Operate to Failure " concept, cost of maintenance, etc. To accomplish this the engineer must possess a thorough understanding of the present maintenance program and have the ability to analyze

Maintenance Significant Item Identification

Part Number & Nomenclature
Part Failure & Detection Analysis
Part Failure History

Reference
Historical Maintenance Records
Maintenance Allocation Charts



Explanations:

In the performance of a scheduled preventive maintenance task, items may be removed because of deterioration but, are repairable and would be scheduled for repair/overhaul at some location. This area of the logic identifies the final cost-effective operations resulting from the original scheduled maintenance task(s). It is not to be construed that minor repair actions could not be completed at previous levels, where nesessary.

Figure 5-31. Inputs Required To Answer Question No. 21.

the appropriate maintenance records to determine the effectiveness of the current maintenance requirements. He must be able to utilize these records to detect failure modes, interpret trends and identify ways to arrest the unfavorable trends.

A knowledge of related system/equipment maintenance and support concepts is highly desirable in order to identify similarities of the systems/equipment and to conclude that certain requirements and maintenance/test procedures could be applied effectively.

The existing maintenance schedule must be examined. During this examination it will become apparent that some of the existing maintenance requirements will not be identifiable to a maintenance significant item level. Such requirements may include general inspections of the system/equipment, inspection for damage and corrosion, special inspections for specific conditions, sampling, etc. To evaluate the effectiveness of such requirements for inclusion in the maintenance plan, the engineer must rely upon his interpretation of the maintenance records along with applied sound engineering judgement. The output of this evaluation must be merged with the output product of the decision logic into a list of scheduled maintenance requirements with their recommended intervals (frequencies). These requirements must now be formulated into a practical and efficient scheduled maintenance program.

The following must be considered when developing the maintenance program:

1 If there are two or more tasks that require ground support equipment, difficult access, functional checks, and the intervals for these are not coordinated, then place both requirements at the same frequency or one at multiple of the other. This will eliminate duplication of activity.

2 Grouping requirements by maintenance location, work area or functional system is beneficial. The grouping of all requirements with the same interval in a specific location has its advantages, especially if access is time consuming. This may require that the recommended interval of some task become shorter or longer to accommodate this grouping.

3 Limiting special inspections is desirable. Special inspections should be regarded as undesirable and are to be avoided unless absolutely necessary.

4 If there are no safety or mission implications, the recommended frequency for each maintenance task should be extended to the maximum interval possible within the bounds of sound maintenance policy.

Many decisions made in the scheduling of the maintenance tasks affect manhours consumed in performing maintenance and to some extent the structure of the maintenance organization. It is of the utmost importance that the maintenance program be as simple and straightforward as possible. It will then have a much greater probability of being faithfully carried out, especially when it makes sense to the maintenance personnel.

5.3 Work Package No. 3 Comparative Analysis

The Martin Marietta plan for the development of an RCM Program for the system/equipment includes conducting a comparative analysis to identify the advantages afforded by the proposed program relative to the present maintenance program. This comparative analysis will identify the proposed program impact on each of the logistic elements, echelons of maintenance, operational availability, and operational and support costs. The comparative analysis will consist of measuring the RCM program task requirement against the task requirements of the present maintenance program.

To facilitate the comparative analysis, a matrix (Figure 5-32) should be constructed on which the leading particulars of both the RCM and present maintenance programs are to be recorded. The matrix will contain four major columns. Columns two, three, and four will be divided into a group of ten smaller columns. Major columns one, two, three and four will be titled; Maintenance Task Description, Present Maintenance Program, RCM Program and Delta, respectively. Each column in the group of ten smaller columns will bear one of the following headings:

<u>1</u> Mean Time Between Maintenance Actions
<u>2</u> Mean Down Time
<u>3</u> Maintenance Manhours
<u>4</u> Number of Personnel Required
<u>5</u> Skill Levels of Each of the Personnel (Skill specialty codes)
<u>6</u> Maintenance Level
<u>7</u> Test Equipment Requirement
<u>8</u> Facilities Requirement
<u>9</u> Repair Parts Requirement
<u>10</u> Transportation and Handling

In order to keep the entries on the matrix as simple as possible symbols may be selected for use in making certain discrete inputs. The various entries will be made on the matrix in accordance with the following instructions.

A description of each maintenance task contained in the RCM and present maintenance program will be listed in column number one, Maintenance Task Description. Should identical task descriptions appear in both maintenance programs it will be listed a single time. The maintenance task description for those items associated with the proposed RCM program will be obtained from the output of work package no. 2 while the task description for those items associated with the present maintenance program will be obtained from the existing technical publications and maintenance records.

COMPARATIVE ANALYSIS
RESOURCE MATRIX

DATE: ______
SHEET NO. __
PREPARED BY: ______

MAINTENANCE TASK DESCRIPTION	PRESENT MAINT REQMT										RELIABILITY CENTERED MAINTENANCE REQMT										DELTA									
	MTBMA	MDT	MMH	NO. PER	SLEP	M L	TE REQ	FAC REQ	RP REQ	T & H	MTBMA	MDT	MMH	NO. PER	SLEP	M L	TE REQ	FAC REQ	RP REQ	T & H	MTBMA	MDT	MMH	NO. PER	SLEP	M L	TE REQ	FAC REQ	RP REQ	T & H

Figure 5-32. Comparative Matrix

In column two will be listed the leading particulars of each maintenance task listed in column one and associated with the present maintenance program. These leading particulars will be listed in the appropriate sub-columns. Data source for entry in column two will be obtained from existing technical publications and maintenance records.

Column three will contain a listing of the leading particulars of each maintenance task that is listed in column one and associated with the proposed RCM program. These leading particulars will be listed in the appropriate sub-columns. Data source for entry in column three will be obtained from the work sheets prepared under work package no. 1 and the output from work package no. 2.

A comparison of the entries in column two and three will be performed and the results in the form of the delta values will be entered in column four. In addition those maintenance tasks which can be performed simultaneously will be identified in column four.

Once the comparison matrix has been completed an analysis of the entries will be performed and computations made to determine the effect of the proposed RCM program on operational availability. In addition the impact on each of the logistic elements related to each maintenance echelon will also be identified.

Utilizing the Army Forces Planning Cost Handbook and Supply Bulletin (SB 700-20) as well as Martin Marietta Cost Estimating Manual, dollar values will be determined for each of the maintenance items of both the present and RCM programs. These dollar values will be translated into the operational and support costs. The RCM program O&S costs will be added to the implementation costs to obtain total RCM program costs.

A comparison will be made between the present maintenance program O&S costs and the total RCM program costs (O&S plus implementation) to identify the economical advantages associated with the application of the RCM program over the remaining life expectancy of the system/equipment under evaluation.

5.4 Work Package No. 4 Documentation Preparation

Implementation of the RCM program requires that many maintenance instructions be revised to correlate with the new maintenance program requirements. This includes revisions to update; Technical Manuals, Field Manuals, Technical Bulletins, Maintenance Allocation Charts and Maintenance Directives. Changes to these publications will be unique for each system/equipment and must be made in accordance with the requirements, specifications and directives applicable to the system/equipment which they serve. Therefore, providing general instructions for updating the technical publications is not considered appropriate to this document.

6.0 Maintenance Program Integration

Any maintenance program is made up of a number of lesser programs, i.e., scheduled programs of; servicing, preventive maintenance, corrosion control, safety inspections, special inspections, etc., and the non-scheduled corrective maintenance actions, all of which must be integrated into a single, cohesive maintenance program. For example, the scheduling of a hardtime preventive maintenance item must consider the requirement for any safety inspections, overhaul requirements, functional inspection, etc. Whenever, a requirement exists for two or more different types of scheduled maintenance actions to be performed on the same item all maintenance actions should be scheduled to coincide to the maximum extent possible.

Once the preventive tasks have been identified through the decision logic of the RCM program they must be integrated with the other scheduled, companion programs, i.e., corrosion control, safety inspections, etc. Each RCM program task will be evaluated along with the task requirements of the other scheduled maintenance programs to determine which items should be scheduled to be performed concurrently. All preventive maintenance actions will be scheduled into a single, comprehensive program through which maintenance can be performed efficiently and effectively at the least cost.

7.0 Evaluating Scheduled Maintenance Effectiveness

The basic purpose of any preventive maintenance program is to retain the inherent reliability that has been built into a system/equipment by finding and replacing worn or deteriorated parts prior to the occurrence of failure. If the operational availability of the system/equipment falls below an acceptable level, it is possible that the cause might be traced to an insufficient preventive maintenance program. (Note: Many other possible causes also exist.) Conversely if the system/equipment availability is significantly increased through the establishment of a PM program, it may be an indication that the program is too elaborate. An analysis of the program cost would quickly determine if the PM program has been overdone. Therefore, the program effect on availability with its accompanying cost would provide the only concrete means of measuring the PM program effectiveness. However, since it is not practical to prolong program evaluation for the period of time necessary to measure availability and life cycle costs, it is advisable to establish a summarization procedure for the scheduled maintenance task by which the analyst can reasonably evaluate how well the program is meeting its established objective. Listed below are a number of factors which can be extracted from the maintenance and operations records to assist in the analysis.

Measurement Procedure

1 Identify the particular major item for which it is desired to determine PM program effectiveness.

2 Establish the period of time for the program measurement.

3 Extract the following data for the period selected.

a Number of PM maintenance tasks performed by type, i.e., Daily, Weekly, Monthly, etc.

b Number of discrepancies discovered during each type of inspection in each cycle which was anticipated for that type inspection.

c Number of discrepancies discovered during each type of inspection in each cyle which were not anticipated.

d Total number of PM maintenance tasks of all types performed over a given period.

e Number of discrepancies discovered over a given period which were anticipated.

f Number of discrepancies discovered over a given period which were not anticipated.

g Number of missions (or mission hours) performed by the major item in the given period.

h Number of failures or degradations that the major item experienced (if any) during the given period.

4 Compare the information in 3 b and c with that in 3 a to determine whether the scheduled maintenance program is effectively identifying the important discrepancies for a particular type inspection.

5 Compare the data in 3 e and f with that in 3 d to make a similar determination for the overall PM program for the major item concerned.

6 Compare the data in 3 h with that in 3 g to determine if unexpected failures or degradations are occurring that should be averted by the PM inspections.

It is impractical to establish, in this document, any relationship standards or ratio that would be applicable to a large variety of failure modes. Some types of inspections might be expected to detect deterioration or impending failure each time they are performed with subsequent repair expected. Whereas other types, particularly those designed for safety reasons, might be expected to reveal no deterioration; they are conducted to ensure that the condition remains good.

However, a qualitative analysis conducted by knowledgeable and experienced maintenance personnel using sound, engineering judgment should produce information regarding the continued value of performing each specific preventive task as well as the overall effectiveness of the PM program.

APPENDIX B

MARTIN MARIETTA PLAN FOR THE DEVELOPMENT OF A RELIABILITY CENTERED MAINTENANCE PROGRAM FOR EXISTING SYSTEMS/EQUIPMENT

OA 7815-5A

February 1978

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CONTENTS

1.0 SUMMARY

The review and evaluation of the depot mission and activities resulted in the identification of two areas that offered an opportunity to achieve some positive results through the incorporation of an RCM program; (1) the selection of major end items for depot overhaul and (2) the determination of the overhaul task requirements.

As the result of this, two sets of decision logic were developed. One was designed to compliment the On-Condition Inspection process. When used in conjunction with the inspection results, it will provide the means of selecting the most deserving items for depot overhaul, considering both economical and reliability aspects. The other set of logic was designed to determine the specific overhaul task requirements for any given item. This logic, while primarily designed to be used in screening the task requirements for existing systems and equipment, is adaptable to developing requirements to new systems with equally good results. When the logic is properly applied, the results will be DMWRs from which all non-essential and non-economic tasks have been eliminated.

However, RCM cannot be effective unless the DMWRs are revised to delete "Repair or Replace As Necessary" statements and replace them with explicit damage or deterioration limits that can be readily measured.

This document includes a description of the two distinct logic processes developed to impact the depot overhaul program.

2.0 INTRODUCTION

In preparing to conduct a survey to evaluate the Army's implementation of Reliability Centered Maintenance, Martin Marietta found it necessary to develop a baseline plan. As a result, Martin Marietta document OA7815-3 was created. It contained the company's plan for the implementation of RCM for existing systems/ equipment at the field maintenance level. In this current document, the procedure has been extended to cover depot overhaul. This, like OA7815-3, uses the airline industry's MSG-2 concept as the foundation, with additional flexibility incorporated to provide for application to a broad range of systems/equipments. It is not intended as an absolute, inviolate instrument for implementation, but a general definition of Martin Marietta's approach to the application of the RCM concept to depot overhaul, based on its evaluation of the Army's RCM implementation program.

This document, together with OA7815-3, provides the baseline on which an objective evaluation of the Reliability Centered Maintenance Program, as currently applied to existing Army Maintenance Programs, can be performed.

3.0 APPROACH

3.1 General

The initial step in the development of an RCM program for application to depot overhaul was to determine whether the Reliability Centered Maintenance Concept has an application to depot overhaul. If so, the next step was to determine if the overhaul activities can be controlled to eliminate all non-economical and non-essential tasks through the use of decision logic. However, the study team first reviewed the depot mission and the present methods and procedures used to restore equipment for return to stock. A number of government documents, including FM-101-10-1, AMCP 750-2, AMCP 706-132 and AMCC 750-37, were used to understand current Army policies regarding depot overhaul. Additional information was obtained through discussions with Martin Marietta logistics personnel with experience in depot-type operations, preparation of depot maintenance plans, and preparation of Depot Maintenance Work Requirements (DMWR).

From this overview, it was determined that the primary candidate processes with a potential for cost savings through RCM application were:

- selection of major end items for depot overhaul,
- production planning and control, and
- determination of depot task requirements.

The next step was to take a close, in-depth look at each of the selected process areas to determine how each is organized, and to rate its effectiveness in accomplishing its purpose.

Selection of major end items for depot overhaul is made through the application of hard time limit criteria (item has reached a pre-determined age or usage), or the performance of an On-Condition Inspection conducted by teams of trained personnel. Those items sent to depot for overhaul must be in a restorable condition. As a general rule, equipment returned to stock after overhaul must meet original specifications and tolerances, and the restoration work is beyond the capability of lower echelon maintenance. The selection process is discussed in detail in paragraph 3.2.

Planning, programming, and scheduling of depot overhaul maintenance is a large-scale effort. It has been organized into a Production Planning and Control (PPC) System using computers and automatic data processing. The PPC also handles other depot activities such as modification, conversion, alteration, renovation, and fabrication, which are beyond the scope of this study. Paragraph 3.3 contains the results of the PPC system review.

Considerable potential for cost savings was found in work connected with determining the actual overhaul tasks to be accomplished on each group major end item processed through the depot. The policy of restoring units to a like-new condition indicates that cosmetic tasks to restore appearance carry the same weight as reliability-centered tasks. Elimination of these non-essential tasks is most effective at the point of preparing instructions for overhauling personnel. The discussion of this process area is located in paragraph 3.4.

3.2 Selection of Major End Items for Depot Overhaul

There are two primary means of determining that an item is a candidate for depot overhaul: Hard time limit criteria (usage, calendar time, number of cycles, etc.), and conclusions from an On-Condition Inspection.

The hard time determination is based on the item reaching a designated limit of service. It does not consider the condition of the item at that time. The use of this determination does away with the need for equipment inspection or analysis to identify the overhaul requirement. The equipment is marked for depot solely on the basis of time in use.

The On-Condition Inspection is conducted when a major end item reaches a predetermined age since it was new or since its last overhaul. This inspection is conducted on-site by personnel who have been trained for that purpose. Based upon inspection analysis, specific major end items by serial number are selected for delivery to the depot for confirming inspections, maintenance and repair (overhaul).

On-Condition Inspection is an authorized procedure, in which certain key indicators are scrutinized to determine the item's current condition. These key indicators are selected because they are the principle contributors to the overall condition of the major end item. Consequently, they provide a sound indication of the need for depot overhaul. Each indicator is graded on a numerical scale, based on its condition and its importance to the overhaul condition of the major end item. The selection of the indicators and the definition of the numerical values available for delegation to each indicator are necessarily unique for each type of equipment (M-113 is not the same as the VRC-12, for example). Also, the critical threshold, the point at which the numerical value or combination of numerical values indicate the item to be a candidate for depot maintenance, would be unique for the type of system/equipment being inspected.

Of the two selection methods considered for RCM application, only the On-Condition Inspection method presents an opportunity to attain significant results. The process is a viable candidate because decision logic can be easily inserted between the inspection results and unit disposition determination without modification of the established equipment inspection process. The selection logic diagram, Figure 1, displays six decision logic questions designed in consonance with RCM philosophy to provide a method of determining disposition of the major end item inspected. These questions are for application to the On-Condition Inspection outcome of each major end item. The questions are used to evaluate the condition of each major end item, with resultant conclusions dictating one of four possible dispositions.

1 Depot overhaul not required

2 Item is beyond economical repair, and disposition should be in accordance with applicable regulations

3 Overhaul to be deferred to a later date

4 Immediate depot overhaul indicated.

The use of the decision logic questions will in no way restrict or supersede the requirement to consider the production control criteria applied to equipment lots such as economic production rates, economic production quantities, maintenance priorities, available funding, etc. These are necessary considerations for effective planning and programming.

The decision logic consists of the following six questions. Questions 1, 2 and 3 are for evaluating the condition of the item regarding its need for overhaul, while questions 4, 5 and 6 are for identifying external conditions which affect the timing of the overhaul or disposition of the item.

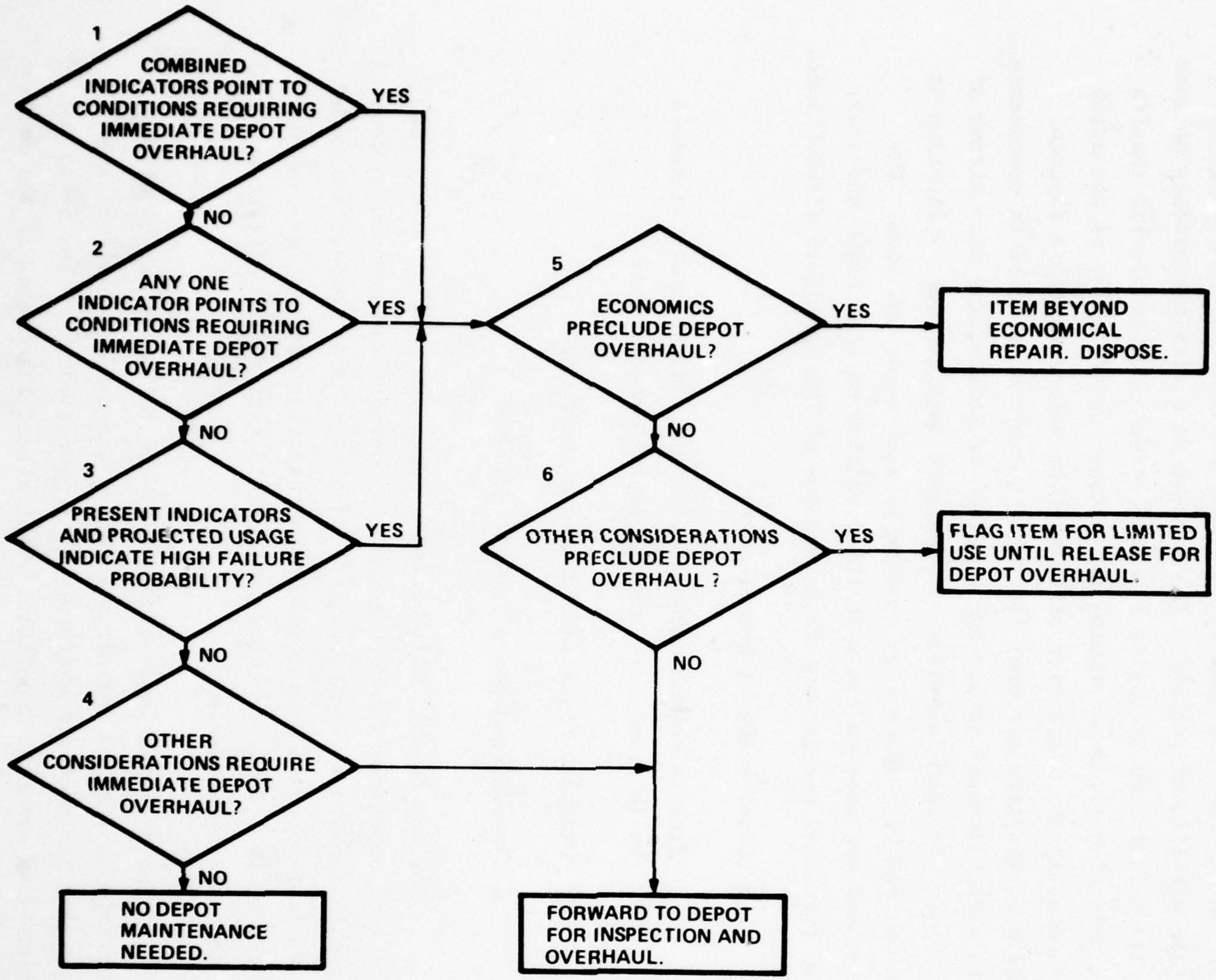

Figure 1. Overhaul Selection Logic

Question #1: Does the inspection of the combination of indicators present evidence of a general condition requiring immediate depot overhaul?

A YES answer would indicate a major end item condition wherein the combination of the numerical values of all the indicators is above the critical threshold requiring depot maintenance. Therefore, immediate maintenance of the major end item is suggested. A NO answer would indicate the general condition of the major end item is good, and no need for immediate depot maintenance exists.

Question #2: Do the results of any specific indicator present evidence of a condition which would require immediate depot maintenance?

A YES answer would indicate the presence of two conditions; (1) The general condition of the major end item is acceptable, but at least one of the indicators has a numerical value above the critical threshold, requiring maintenance, and (2) The repair or replacement of the faulty assembly/sub-assembly is beyond the maintenance capability of the lower echelons (DSU/GSU/Organization). A NO answer would indicate that the general condition of the major item is good and no need exists for immediate depot maintenance. It could also indicate that the required maintenance action is within the capability of a lower echelon.

Question #3: Does an evaluation of the present indicators, combined with the projected usage, indicate a high probability of item failure prior to the next inspection cycle?

A YES answer would indicate the presence of two conditions: (1) The numerical ratings of the indicators are centered near the critical threshold but do not suggest the need for immediate maintenance, and (2) The project usage rate of the item will cause deterioration and would be most likely to be failure prone, requiring

overhaul prior to the next inspection cycle. A NO answer would indicate that no immediate maintenance is required, although the numerical ratings of the indicators are approaching the critical threshold. In addition, the expected usage will be such that excessive deterioration will not occur prior to the next inspection cycle.

Question #4: Are there other considerations which dictate a requirement for immediate depot maintenance?

A YES answer would indicate that there are circumstances such as need for modification, which would require the major end item to be forwarded to the depot. It would be advantageous to schedule overhaul at the same time. A NO answer would indicate that there are no requirements for forwarding the major end item to the depot. Therefore, no depot maintenance should be scheduled.

Question #5: Are there economic considerations which preclude the performance of depot maintenance?

A YES answer would indicate that the estimated cost of repair exceeds economical repair criteria. Disposition of the major end item should be made. A NO answer would indicate that the estimate maintenance cost is within the threshold established for overhaul of the item.

Question #6: Are there other considerations that take precedence and preclude the immediate scheduling of depot maintenance?

A YES answer would indicate that there are reasons such as alert status or the lack of replacement items, which would prevent the immediate performance of depot maintenance. A NO answer would indicate that there are no circumstances sufficient to delay the scheduling of depot maintenance.

Table I contains a matrix showing all possible combinations of answers to the six decision logic questions which result in the four possible actions.

3.3 Production Planning and Control

Workload requirements for each depot are initially determined by the National Inventory Control Point. They are issued through the U.S. Army Major Item Data Agency (USAMIDA) as part of the Production Planning and Control System (PPC). The PPC is applicable to the planning, programming, and scheduling of depot maintenance, as well as modification, conversion, alternation, renovation, and fabrication. The required schedules, priorities, and identification of work to be accomplished are provided through the system by USAMIDA, along with control data such as program control number, item identification, procurement request order number, customer, work accomplishment code, and unit cost estimates.

To the greatest extent possible, the PPC embodies the principle of management by exception. To adhere to this principle, automatic data processing is used extensively for providing direction and compiling follow-up information.

Maintenance data are exchanged between the various maintenance depots and USAMIDA. Depot maintenance engineering data are collected and reported in accordance with AMCC 750-2, Data Maintenance Capability/Capacity, and Engineering Data Report. The data collected are reported to USAMIDA and filed in the depot maintenance data bank, the official source in making management decisions. PPC documentation flow is shown in Figure 2.

TABLE I

POSSIBLE COMBINATIONS OF ANSWERS TO SELECTION LOGIC QUESTIONS

QUESTION NO.	DEPOT REPAIR NOT INDICATED	ITEM BEYOND ECONOMICAL REPAIR			ITEM SCHEDULED FOR LATER DEPOT ACTION			DEPOT REPAIR INDICATED IMMEDIATELY			
1	NO	YES	NO	NO	YES	NO	NO	YES	NO	NO	NO
2	NO		YES	NO		YES	NO		YES	NO	NO
3	NO			YES			YES		NO	YES	NO
4	NO										YES
5		YES	YES	YES	NO	NO	NO	NO	NO	NO	
6					YES	YES	YES	NO	NO	NO	

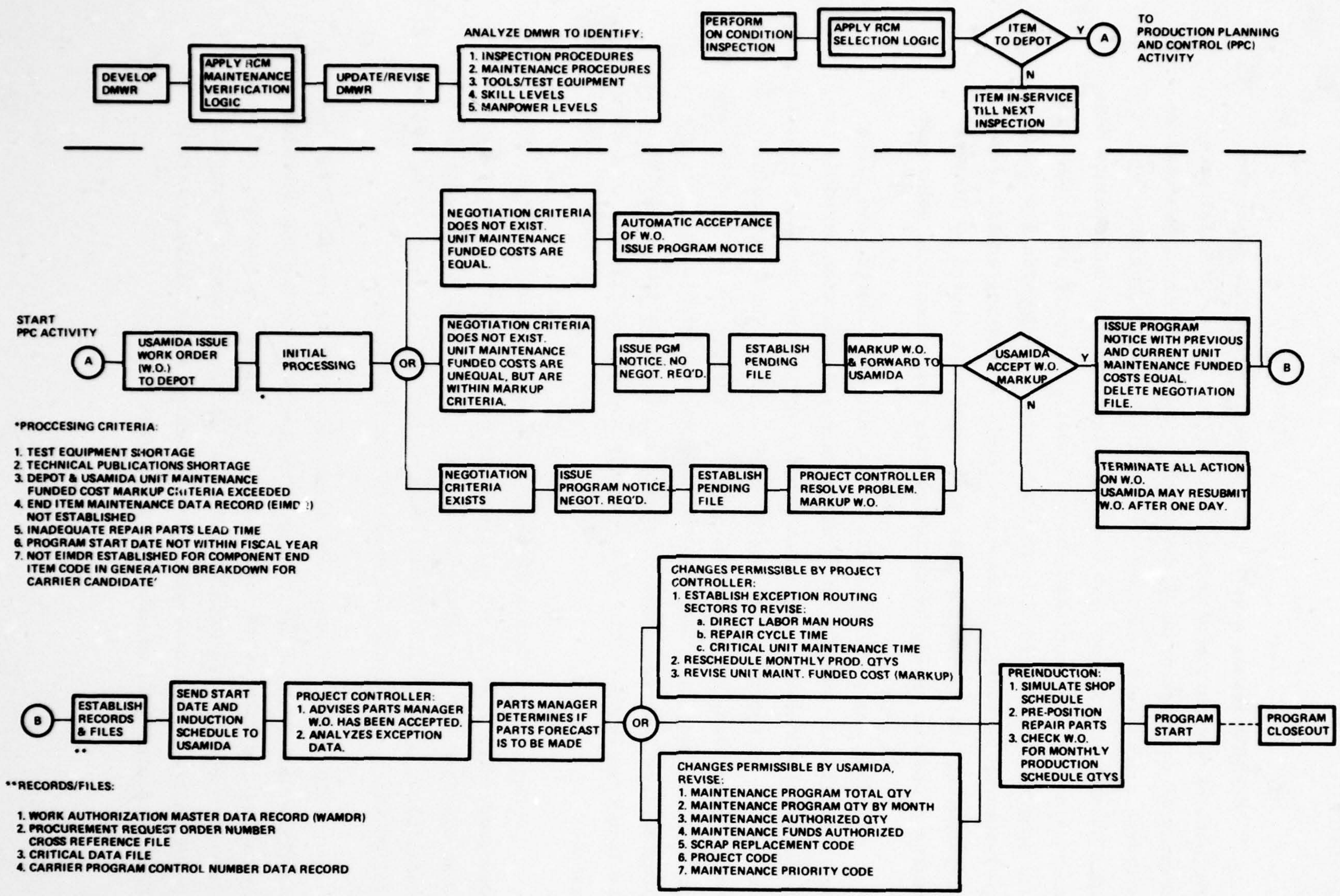

Figure 2. RCM Impact - Depot Production Planning and Control

USAMIDA issues a work order to the appropriate depot for overhaul of a quantity of specific major end items. Initial processing of the work order is begun to determine if these negotiation criteria exist: test equipment or technical publication shortages, unit maintenance funded cost discrepancies, end item maintenance data, records not in the depot data bank, inadequate repair parts lead time, and program start conflict. The work order is automatically accepted as issued or is subject to markup to resolve existing negotiation differences. Markup of the work order must be accepted by USAMIDA before a program notice establishing firm requirements is generated.

After the program notice is issued, data records and files are established, and a program start date and induction schedule are forwarded to USAMIDA. The depot project controller advises the parts manager of acceptance of the work order. He, in turn, determines parts forecasting requirements. Specific changes to the overhaul program by the project controller and USAMIDA are permissible prior to program start, as indicated in Figure 2. Pre-induction activities include simulation of the shop schedule and pre-positioning of repair parts.

For accomplishment of the actual overhaul work, a depot may use production line, a bay shop or work bench operations, depending upon the item and the cost of the work. The shops contain extensive facilities, specialized production equipment and a diversity of skills, all of which are within the scope of the PPC system.

The number of major end items returning to the depot for overhaul will probably be changed when the RCM concept and decision logic are implemented in the On-Condition Inspection process, and an impact to PPC will be experienced. An additional impact is anticipated as the result of application of design logic to the overhaul task determination, as outlined in paragraph 3.4.

But other than these effects, illustrated in Figure 2, RCM is not directly applicable to depot programming. The depot program, i.e., production layout, maintenance production quantities, skill requirements, resources, schedules, etc. is economically optimized through the automated PPC system, which includes automatic feedback of data concerning the overhaul program results. Any improvements to the current system are more likely to be achieved through a study directed to this purpose alone, rather than through the application of RCM principles.

3.4 Depot Task Determination

One of the keys to controlling expenditures during overhaul is the development and disciplined use of decision logic in updating and revising the DMWR for each type of equipment. After equipment has been fielded for a period of time, service and inspection records should indicate what items are most susceptible to deterioration or breakdown in operational service. These thereby become the drivers for repair or overhaul. Others may be shown to require a low incidence of rework, indicating that overhaul of these portions can be reduced in frequency. This reduction is particularly cost-effective if their high durability in service was not anticipated when the DMWR was originally written.

Repair or replace as necessary statements should be deleted from DMWR instructions. They should be replaced with explicit damage or deterioration limits (tolerances) that can be measured by inspection and test procedures. When the tolerance limits have been exceeded, the required overhaul tasks should be clearly specified. Delineation of the amount of work, methods, procedures and standards of repair should be sufficient only to restore the item to specified tolerances.

For some types of equipment, a 100 percent teardown of the major end item is a reasonable overhaul policy. An understanding of the nature of the equipment and experience with the types and frequencies of

failures peculiar to such equipment have indicated that 100% teardown is the only practical overhaul method for restoring the designed inherent reliability. The DMWR for this type equipment probably will be retained substantially as originally written when field experience is reviewed. Considerable change is possible but not anticipated.

The DMWR documents for the majority of military equipment types should be prime candidates for review and possible updating, either in correlation with design modifications or when a group of major end items is designated for depot overhaul. The original DMWR instructions are usually based upon anticipated equipment usage under predicted environmental conditions and these conditions may have changed. In addition, new fabrication, manufacturing and overhaul techniques are being developed constantly. These can outdate procedures written several years previous to the work date.

Along with elimination of nonessential tasks, the DMWR revision would identify additional tasks, if they can be accomplished with little or no additional cost, or if they can significantly contribute to restoration of the item's reliability.

The following examples are typical cases for consideration and for application of RCM decision logic.

1 During a required task, parts may be exposed which are not designated for overhaul per the last revision of the DMWR. The RCM logic can accurately determine if it is economical to rebuild or replace the parts, and will show if such action will contribute significantly to item serviceability.

2 During a required task, it may become necessary to remove some serviceable parts in order to gain access to a faulty component. In this case, the logic application should decide whether there are advantages to be gained in exchanging the removed parts for new ones, when there is no labor cost for this action.

3 In some cases, a currently moderate-failure-rate item has not been previously identified for overhaul rework or replacement. The decision logic can be applied to ascertain the relative importance of economic or reliability justifications concerned with reworking or replacing the part during the item overhaul.

The RCM is ideally suited to review and update DMWR documents. It can be directly related to the pertinent considerations involved with overhaul task definition. Although a preshop analysis (PSA) is performed on each item of equipment to determine work needed, the overhaul instructions resulting from that analysis are not comprehensive. Inspection personnel do not possess all of the engineering design information available to the project office, nor are they aware of the maintenance history on the equipment type. The commodity command engineers are obviously best situated to provide a thorough and complete listing of depot overhaul tasks, in the form of a revised DWMR.

The baseline information for updating the DMWR could be obtained from the output of a computer program, which would identify the level of overhaul needed. This would be the same program used for selecting overhaul candidate items. The modeling input data would consist of operational experience, maintenance information, field inspections, condition indicators, criteria, and weight factors, plus engineering development reports on reliability predictions and pre-deployment demonstration testing.

The updated DMWR supplied for depot use should specify maintenance standards to be met, tolerances required and procedural data, in order to eliminate the permissiveness that leads to unnecessary replacement or overwork of item parts. The DMWR should be a comprehensive document that establishes serviceability criteria for all elements and components. It should not permit the removal or repair

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of any element or component unless it can be shown to be out of tolerance or unserviceable.

The key to success in achieving a reliable and economical overhaul is the application of the decision logic. The logic should provide answers to these questions when applied to the revision of the DMWR:

1 Is there a valid economic reason for performance of the task?

2 If the task is not performed, what will be the effect on the item's reliability during its service life?

3 Could the task be postponed to a later date without undue risk to serviceability?

4 What is the most economical method of performing the task to restore inherent reliability of the major end item?

The depot task determination logic diagram (Figure 3) has been developed to assist engineers or analysts in determining the precise limit of necessary and economical work to be performed during depot overhaul, in order to restore the end item to usable condition for stock issue. This logic diagram consists of nine questions which are stated in general, abbreviated terms. The factors affecting each decision point will vary, due to the wide variety of equipment requiring DMWR instructions. A question designed to fit one type of equipment, would not, in all probability, be accurate for another type.

Some of the factors, pertinent in varying degrees to each of the ten questions, are: (1) operating and environmental conditions experienced by the equipment, (2) design limitations, (3) vulnerability in combat, (4) hours of service, (5) length and type of

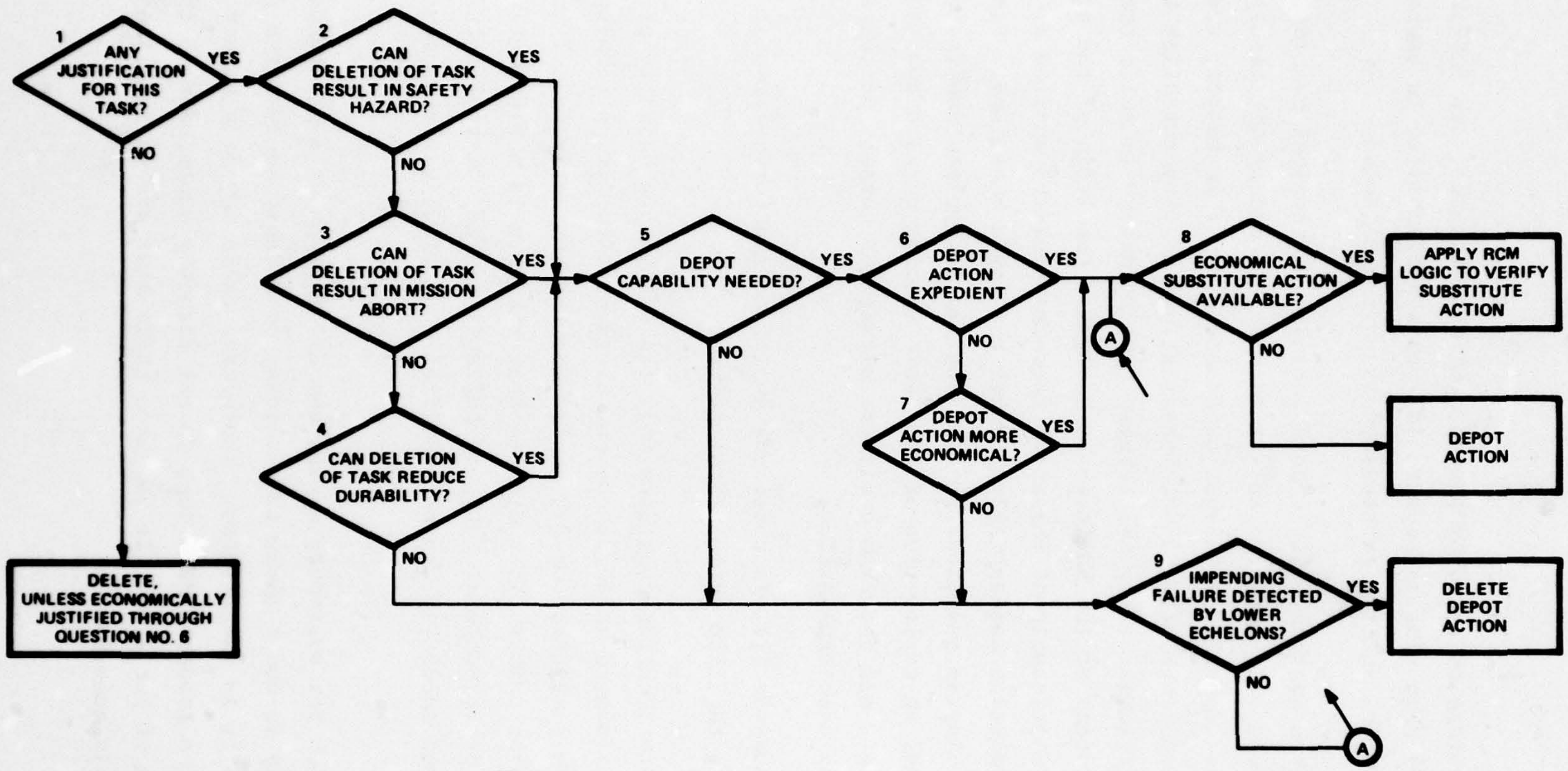

Figure 3. Task Designation Logic

dormant storage or stand-by status, (6) mean time between failure (MTBF), (7) mean time to repair, (8) parts availability in operational service, and (9) maintenance support available.

These factors, plus others including economical considerations, should be quantified as far as possible and qualitatively weighted in answering the logic questions. For this reason, the diagram questions are not all-encompassing, nor do they establish hard and fast criteria. They are trigger type in nature to guide the thought process of the engineer or analyst. Knowledge of the equipment and relationship of the above factors should be applied as each task is processed sequentially through the logic questions. Since the logic diagram questions are necessarily incomplete due to space limitations, an explanation of the basic meaning of each question is given below. All possible equipment situations cannot, of course be included in each explanation.

Question #1: Is there any justification for performing this task during the life cycle of the item?

This question considers only the elementary validity of the task. If a single valid reason can be identified for performing the task, it is justification for continuing the RCM analysis. If no justification exists, it indicates that the task is not essential to equipment performance, safety, or reliability and the task should not be performed unless it can be justified economically with some other task.

When the engineer, during the development of a maintenance program, is in doubt about the validity of a task, he is often prone to include it in the program. Therefore, there may be a number of tasks in the present DMWRs that do not directly contribute to the well-being of the item. It is these tasks that are to be eliminated through this question.

A YES answer indicates that the task under consideration has validity, and should be subjected to the balance of the decision logic.

A NO answer indicates that the task is of no specific value and should be deleted unless it could be combined with another task for greater economy. An example of this could be: (1) painting of valve covers on a vehicle engine, (2) stenciling of casual service instructions on equipment that is maintained by trained personnel.

Question #2: Could failure to perform this task introduce a safety hazard failure?

This question addresses the possibility that there would be a high probability of the occurrance of failure in a mode that would result in personnel injury or equipment damage if the task is not performed.

To answer this question requires a tradeoff between the risk of not performing the task and the potential cost savings. Increasing the normal risk to personnel and equipment to an unacceptable level to save money is obviously unwise and may well prove to be uneconomical in the long run.

A YES answer indicates that failure to perform the task would result in a high failure probability, accompanied by unacceptable risk of a safety hazard.

A NO answer indicates that failure to perform the task would result in one of two conditions: (1) there would be no impact on safety or (2) that the impact would be within acceptable units.

Question #3: Can failure to perform this task result in mission abort?

This question considers the possibility of a failure which would prevent the successful completion of the mission, if the task is not performed.

To answer this question calls for a logic process and calculations similar to those involving safety, including quantitive evaluation of failures experienced in operational usage. Deletion of the task could have a pronounced effect on the equipment reliability. It therefore requires careful analysis.

An aborted mission can be very costly in terms of man hours expended, energy consumed, and objectives unfulfilled, and could more than offset any maintenance cost savings.

A YES answer indicates that not performing the task could result in a high probability of failure of a nature that would cause an abort.

A NO answer indicates that failure to perform the task would not change the failure probability from the norm.

Question #4: Could failure to perform this task result in reduced durability?

This question addresses the possibility that the useful service life of the item could drastically be reduced if overhaul is not performed.

Although not as critical as safety or as expensive as mission abort, the failure of an item to survive its normal service life could have some very adverse affects. It could result in costly maintenance and excessive nonavailability. The potential savings from overhaul task deletion could be easily offset by early wearout of the item.

Here again, as in the previous questions, all the operational, environmental, reliability, and maintainability factors will impact the decision.

A YES answer indicates that by not performing the task there is a high probability that the service life of the item would be shortened significantly.

A NO answer indicates that failure to perform the task would not result in any change in durability.

Question #5: Is depot capability needed for this task?

This question determines what skills, tools, test equipment, and facilities are needed to perform the task, and their availability at field and depot levels. Also examined are the capabilities needed to achieve the required tolerances and quality.

A YES answer would indicate that only the depot has the means to properly perform the task.

A NO answer means that the lower echelons possess all that is necessary for accomplishing the task.

Question #6: Is depot action indicated for expedient maintenance?

Maintenance expediency concerns the practicality of performing tasks previously considered nonessential or noneconomical, as essential tasks are performed. For example, when an assembly essential to the overhaul is removed, access is provided to an item whose overhaul is non-essential. Consideration should be given to overhauling the exposed item. Again, when it is necessary to remove an item whose overhaul is nonessential to gain access to an essential item, consideration should be given to replacing the nonessential item with a serviceable spare. Economics should govern the decision.

A YES answer would indicate that it would be cost effective to perform the added task while the major end item is undergoing overhaul.

A NO answer would indicate that there is no compelling reason for performing the additional maintenance.

Question #7: Is depot action more economical than lower echelon maintenance?

This question deals with the relative cost of performing an overhaul at depot as opposed to performing On Condition or Condition Monitoring and corrective maintenance in the field. Although most of the preceeding questions have considered some elements of economics, other factors such as cost of facilities, facility utilization, and utilization of personnel must be considered.

A YES answer means depot overhaul for this task is the most cost effective.

A NO answer would mean it is more cost effective to delete the depot requirement for this task.

Question #8: Can impending failure of the item be detected by lower echelon personnel?

This question addresses the capability of lower echelon personnel (operator, organizational maintenance DSU and GSU) to detect a deteriorating condition in time to perform corrective maintenance to avert a failure. When capability exists to detect and correct a deteriorating condition, consideration should be given to deleting depot overhaul action in favor of field maintenance, if indeed field maintenance would prove more cost effective.

A YES answer would mean that it would be cost effective to eliminate the depot task in favor of a field maintenance task.

A NO answer indicates that it would be wise to perform the depot task in order to prevent the possibility of failure.

Question #9: Is there an economical substitute action available for this task?

A consideration of possible substitution also has a cost savings potential. It is often more effective to repair an item than replace it, or vice versa, due to many factors such as material composition changes, new production methods, labor costs, and availability in the supply system. It is possible that a substitute action will produce a superior end item at lower cost.

A YES answer indicates a substitute action has been identified for the task being evaluated. It is now necessary to process the substitute task through this decision logic independently, to obtain a valid comparison of cost and feasibility.

A NO answer indicates that no substitute action has been identified. Therefore, the present task should remain in the DMWR unchanged.

4.0 CONCLUSIONS AND RECOMMENDATIONS

From the study of the depot mission and activities, it was concluded that Reliability Centered Maintenance concept has application to the depot overhaul process. It can be an effective tool for eliminating noneconomical and nonessential tasks.

Of the three areas in which this study was concentrated, the selection of specific major end items for overhaul and the determination of overhaul task requirements are found to offer an opportunity for the incorporation of an RCM program. In the Production Planning and Control area no application was found for the RCM concept. The present method of production planning and control of the depot overhaul activities, via the use of Automatic Data Processing system, supports the RCM concept by adjustment of the overhaul task schedules, labor, parts facility, requirements, etc., through its automatic feedback and self-correcting characteristic. It is possible that in some areas of the PPC system, cost reductions could be identified in a separate study of that system. However, it is doubtful that RCM will ever have a direct role in the PPC area. RCM is maintenance oriented, rather than applying to the functions of receiving, scheduling, costing, reporting and other planning and control elements.

The selection of specific major end items for overhaul through the On-Condition Inspection process was found to be a reasonable candidate for the application of the RCM concept. This inspection procedure has been implemented primarily to reduce the current high costs of depot activities, by eliminating from overhaul consideration equipment which shows some need for additional service at the time of the On-Condition inspection. The six RCM decision logic questions in this study enhance this objective, as the logic is constructed to screen the inspection results to determine which of four alternatives is best suited for disposition of the major end item.

It is recommended that the six-question decision logic selection criteria presented should be incorporated into the On-Condition Inspection Process. However, due to their general nature, it may be necessary to reconstruct some of the questions in order to address the specific needs of the item.

The use of the On-Condition Inspection Process with the decision logic incorporated will provide the means for selecting the most deserving items for depot overhaul, while considering economy and reliability aspects.

The determination of depot overhaul tasks was found to be an ideal area for application of RCM principles. The DMWRs currently in circulation should be reviewed and revised if necessary with consideration of RCM logic. This same conclusion would apply to preparation of any new DMWR published. It is considered vital to the achievement of RCM cost savings that any DMWR used must contain explicit deterioration limits for justification of rework, delineation of exact amount of work to be done, methods, procedures and standards, plus definitive inspection requirements, and prohibition of any unlisted task. Without absolute delineation of each work detail in the DMWR, the implementation of RCM strategy in the depot overhaul process will be ineffectual in producing significant economics.

It is recommended that RCM be fully incorporated in the process of determining tasks to be accomplished in depot overhaul, and that the process be fully and exclusively delegated to the commodity command having responsibility for the major end item's acquisition and maintenance budget.